

# Overview of NICAM: global cloud-resolving simulations and development

M. Satoh

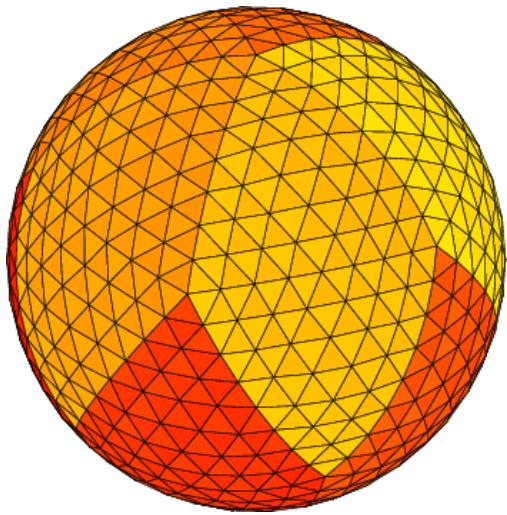
Research Institute for Global Change, JAMSTEC  
Center for Climate System Research, Univ. of Tokyo  
<http://nicam.jp>

Refer to K. Oouchi's talk on Tuesday

Workshop on “High-Resolution Climate Modeling”  
August 10 - 14, 2009

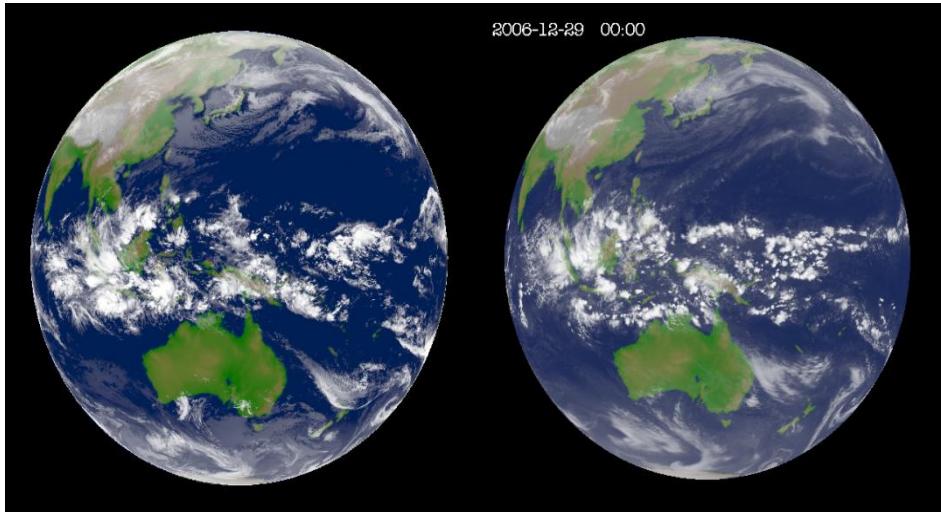
Adriatico Guesthouse - Kastler Lecture Hall  
The Abdus Salam International Center for Theoretical Physics  
Trieste, Italy

# Outlines



MTSAT-1R, IR

NICAM 3.5km, OLR



- Overview of NICAM

Miura et al.(2007, Science)

Nonhydrostatic ICosahedral Atmospheric Model  
for Global Cloud-Resolving Simulations

- NICAM simulations

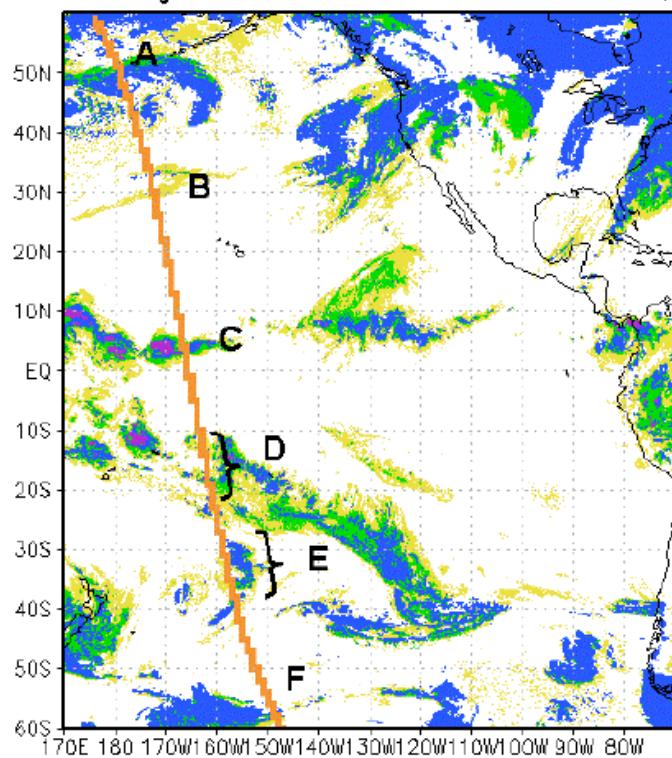
–MJO, TCs, monsoons, precipitation, diurnal variations & cloud properties

- Summary and Future plans

# Ice cloud evaluation by split windows

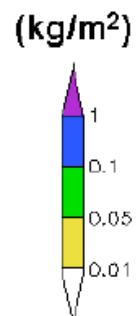
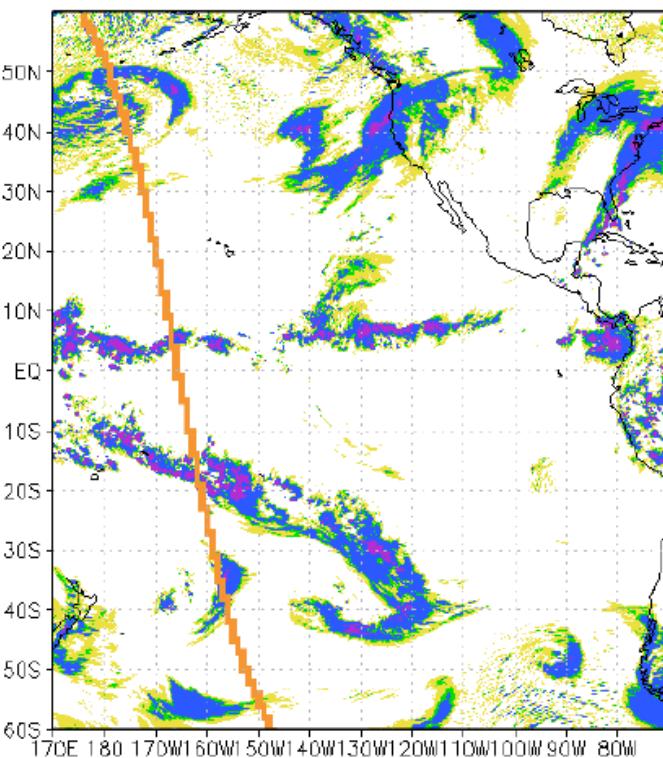
GOES-W Cloud ice(split window)

GOES-W High-level Cloud 00UTC 26 Dec, 2006



NICAM 3.5km Cloud Ice+snow

NICAM ICE+SNOW 00UTC 26 Dec, 2006



Inoue, T., Satoh, M., Hagihara, Y., Miura, H., Schmetz, J. (2009)  
Comparison of high-level clouds represented in a global cloud-system  
resolving model with CALIPSO/CloudSat and geostationary satellite  
observations. *J. Geophys. Res.*, submitted

# NICAM

- Nonhydrostatic Icosahedral Atmospheric Model

Development since 2000

Tomita and Satoh(2005, *Fluid Dyn. Res.*)

Satoh et al.(2008, *J. Comp. Phys.*)

First global  $dx=3.5\text{km}$  run in 2004

Tomita et al.(2005, *Geophys. Res. Lett.*)

- Icosahedral grid

Spring dynamics smoothing

Second order accuracy

Tomita et al.(2001, *J. Comp. Phys.*), Tomita et al.(2002, *J. Comp. Phys.*)

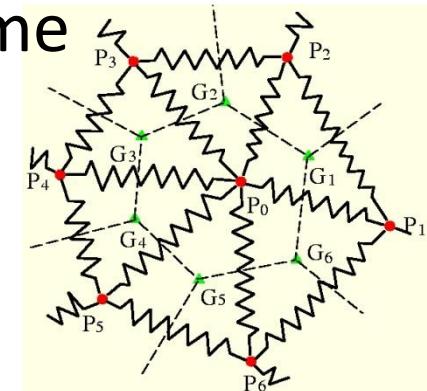
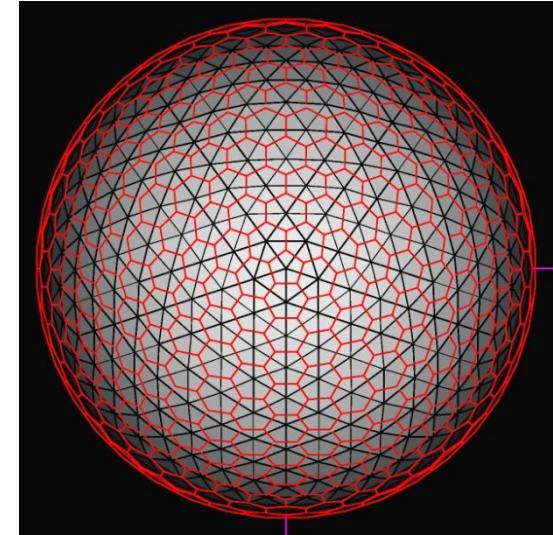
- Flux-form conservative nonhydrostatic scheme

Split-explicit time integration

Mass, total energy & momentum conserving

Satoh (2002, *Mon. Wea. Rev.*)

Satoh (2003, *Mon. Wea. Rev.*)



# Model description

## ■ Dynamics

governing equations	Fully compressible non-hydrostatic system
spatial discretization	Finite Volume Method
horizontal grid configuration	Icosahedral grid
vertical grid configuration	Lorenz grid
topography	Terrain-following coordinate
conservation	Total mass, total energy
temporal scheme	Slow mode - explicit scheme ( RK2, RK3 ) Fast mode - Horizontal Explicit Vertical Implicit scheme

## ■ Physics

radiation	MSTRNX / MSTRNX-AR5 (Sekiguchi and Nakajima, 2008)
cloud physics	Grabowski(1998); NSW6(Tomita 2008); NDW6(Seiki 2009)
shallow clouds	MYNN2 , 2.5 or 3 (Nakanishi and Niino 2004)
boundary layer	
surface flux	Louis(1979), Uno et al.(1995)
surface processes	SST specified & bucket / slab ocean & MATSIRO

# NICAM simulations

- Boreal winter, 2006, 3.5km a week, 7km a month
  - H. Miura
- Boreal summer, 2004; 7km 3months, 14km 5months
  - K. Oouchi , A. Noda
- Ensemble exp. for TC cyclogenesis
  - H. Taniguchi, W. Yanase
- Aerosol coupling exp.(Jul 2006; Nov 2006)
  - K. Suzuki, T. Seiki
- APE, Global Warming-conditions
  - H. Tomita, S. Iga; K. Oouchi, Y. Yamada; Y. Tsushima
- Regional NICAM using coordinate transformation

# NICAM SIMULATIONS

- MJO simulations
- Tropical cyclones
- Monsoon simulations, ISVs and TCs
- Diurnal variability, cloud properties

# NICAM simulation: MJO Experiment

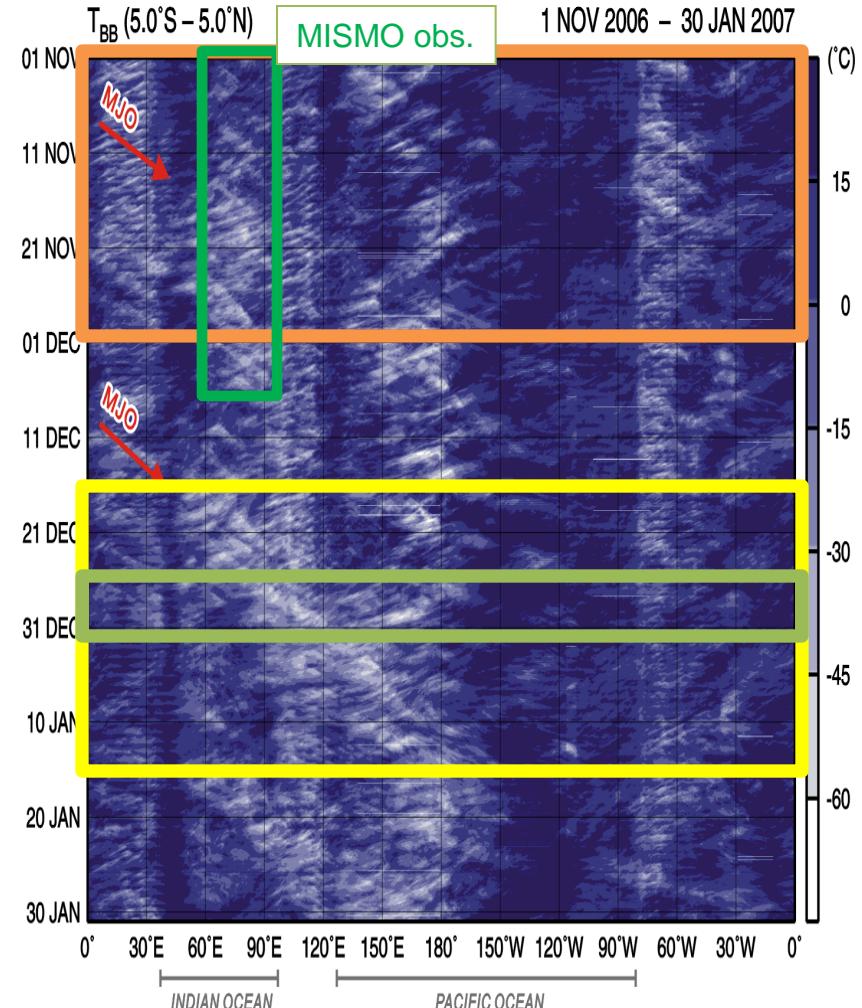
Horizontal grid spacing:  
14 km, 7 km, 3.5 km

Vertical domain  
0 m ~ 38,000 m  
40-levels (stretching grid)

Integration:  
7km, 14km runs: 30 days from 15 Dec 2006  
7km, 14km runs: 30 days from 1 Nov 2006  
3.5km run: 7 days from 25 Dec 2006

Initial conditions:  
Interpolated from NCEP tropospheric analyses  
(6 hourly, 1.0x1.0 degree grids)

Boundary conditions:  
Reynolds SST, Sea ICE (weekly data)  
ETOPO-5 topography, Matthews vegetation  
UGAMP ozone climatology (for AMPI2)

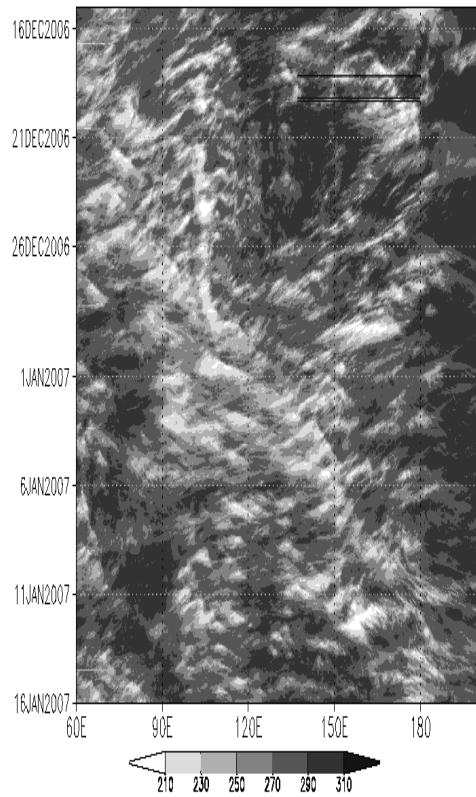


- EXP. Dec 2006: Miura et al.(2007, Science), Nasuno et al.(2009,JMSJ),  
Fudeyasu et al. (2009, GRL), Liu et al. (2009, MWR)
- EXP. Nov. 2006 (MISMO): Miura et al. (2009, GRL)

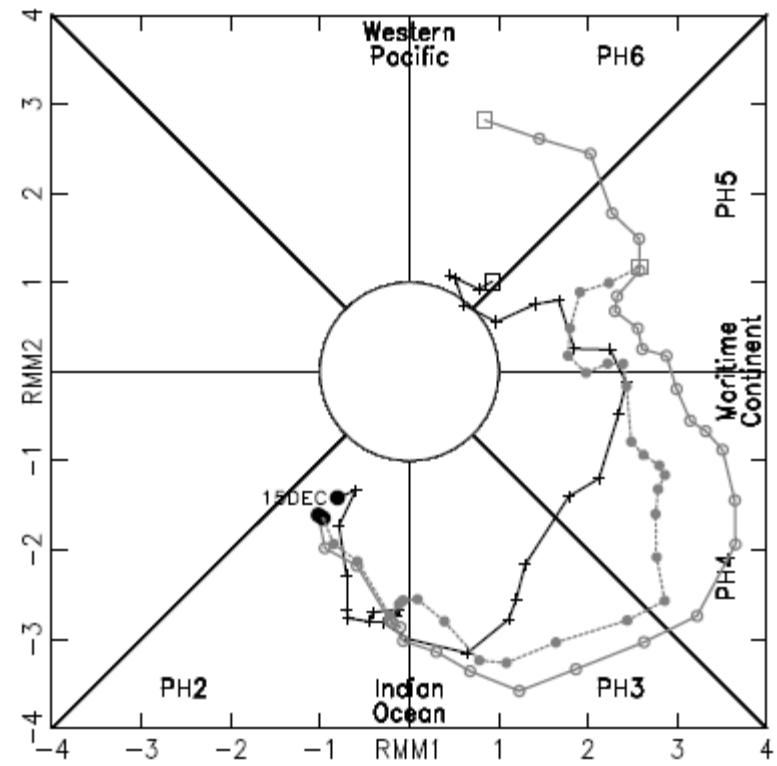
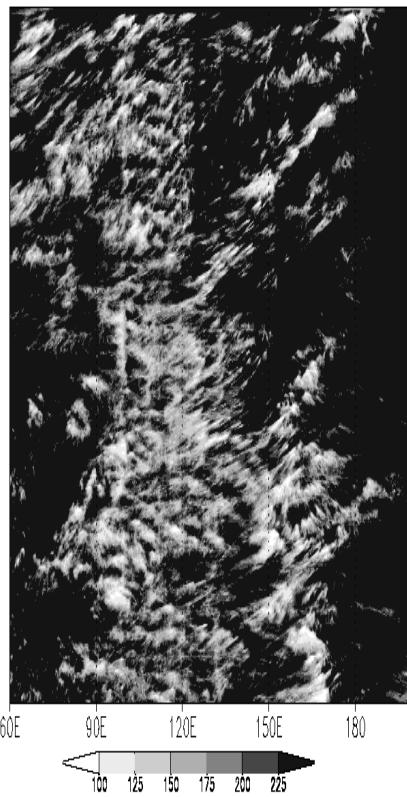
# Realistic MJO simulation

Miura et al.(2007, Science), Nasuno et al.(2009, JMSJ),  
Fudeyasu et al. (2009, GRL), Liu et al. (2009, MWR)

NCEP/CPC IR

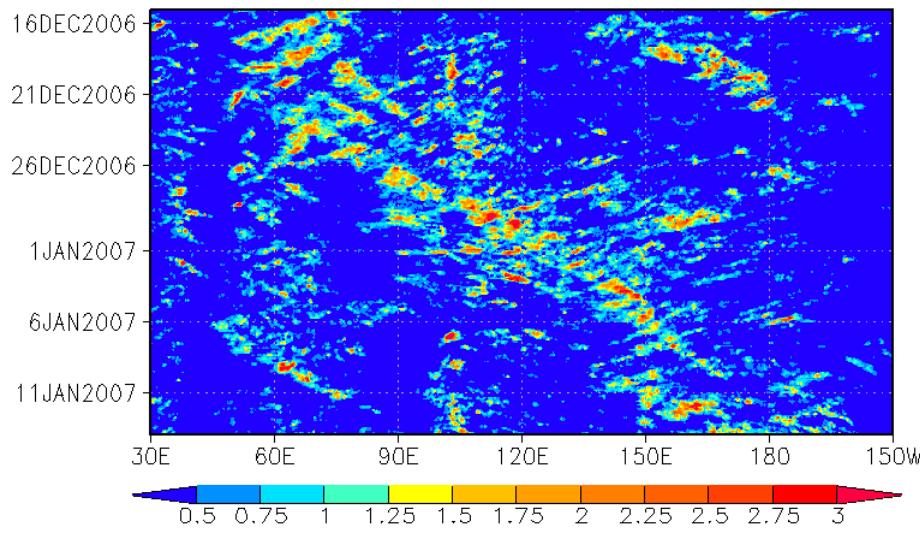


NICAM 7km, OLR

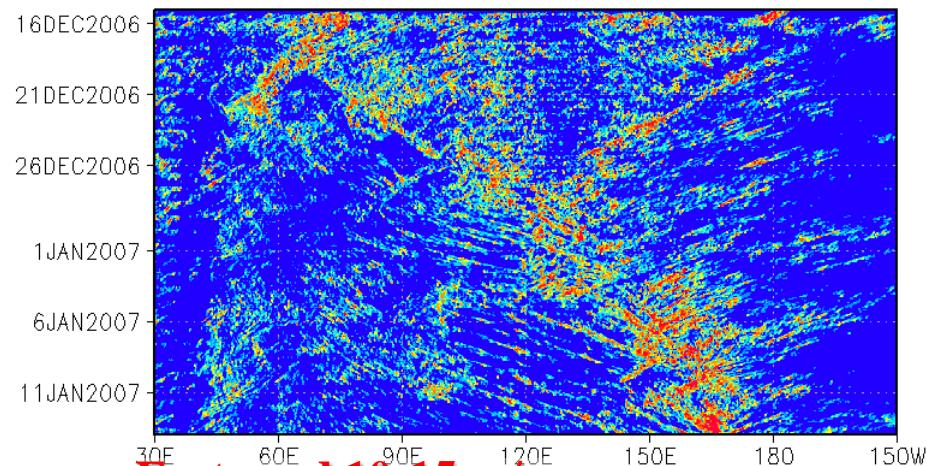


# Hovmöller diagrams: precipitation, temperature

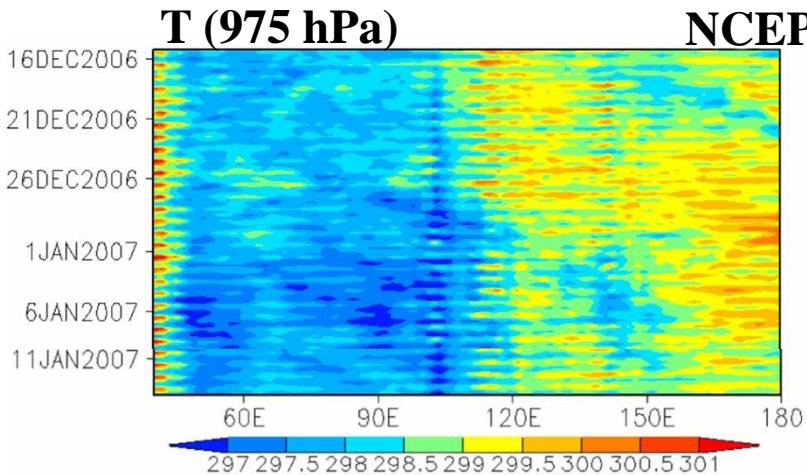
Precipitation (10S-5N) TRMM PR



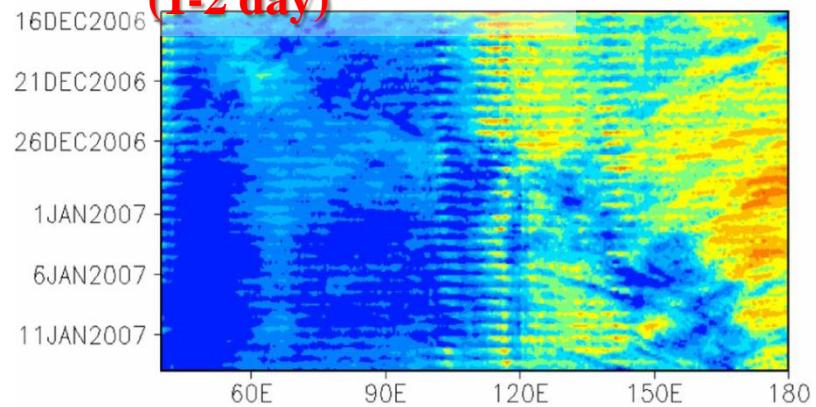
NICAM  $dx=7$  km



**Eastward 10-15 m/s  
1000-2000 km  
(1-2 day)**

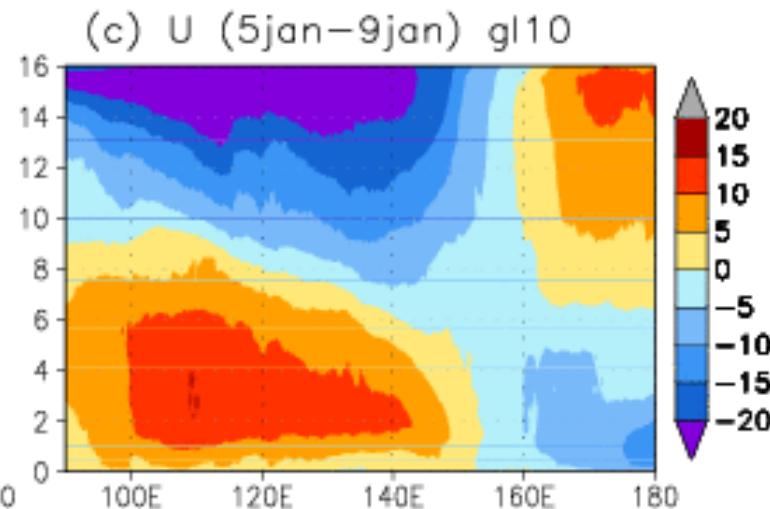
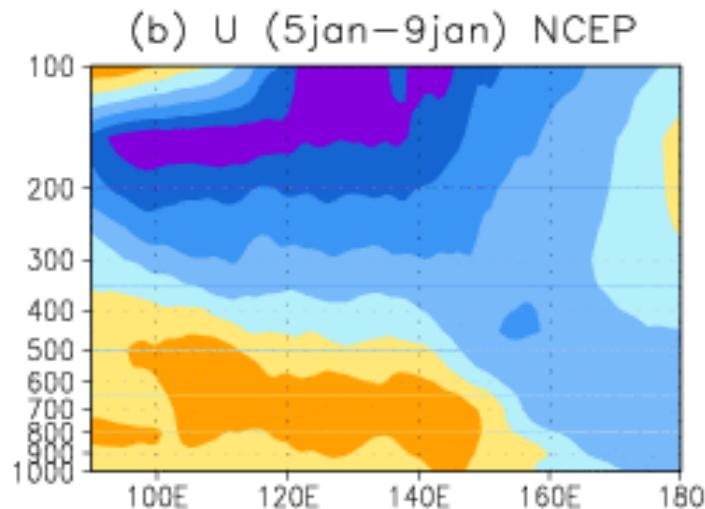
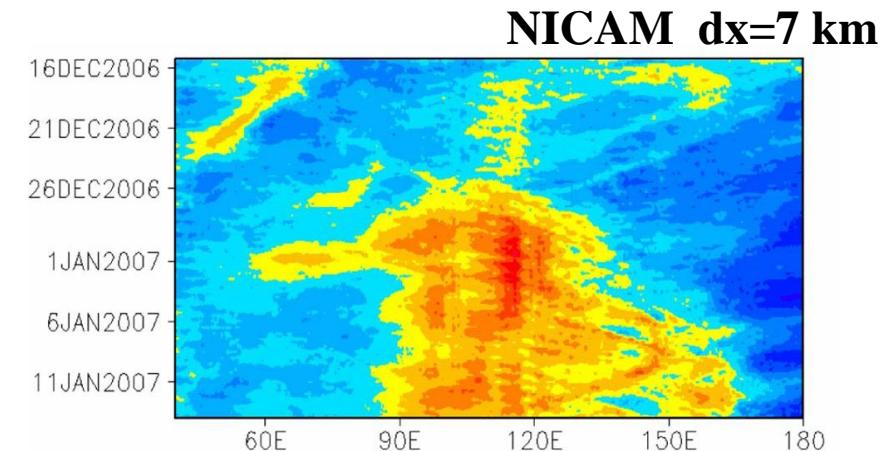
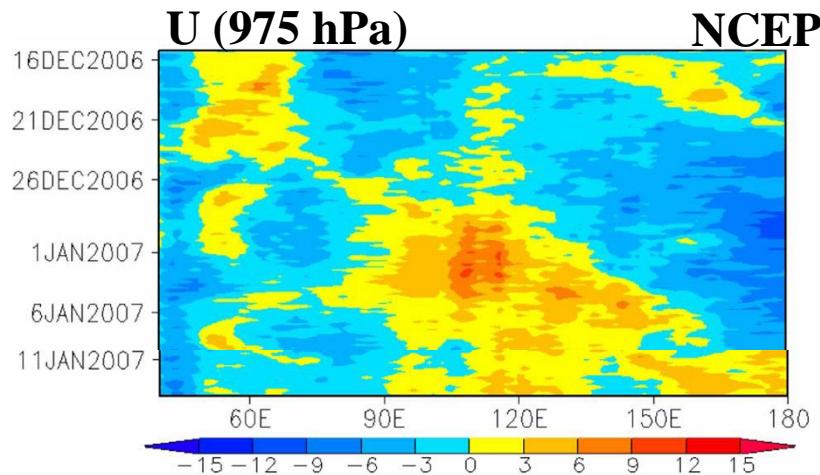


NICAM  $dx=7$  km



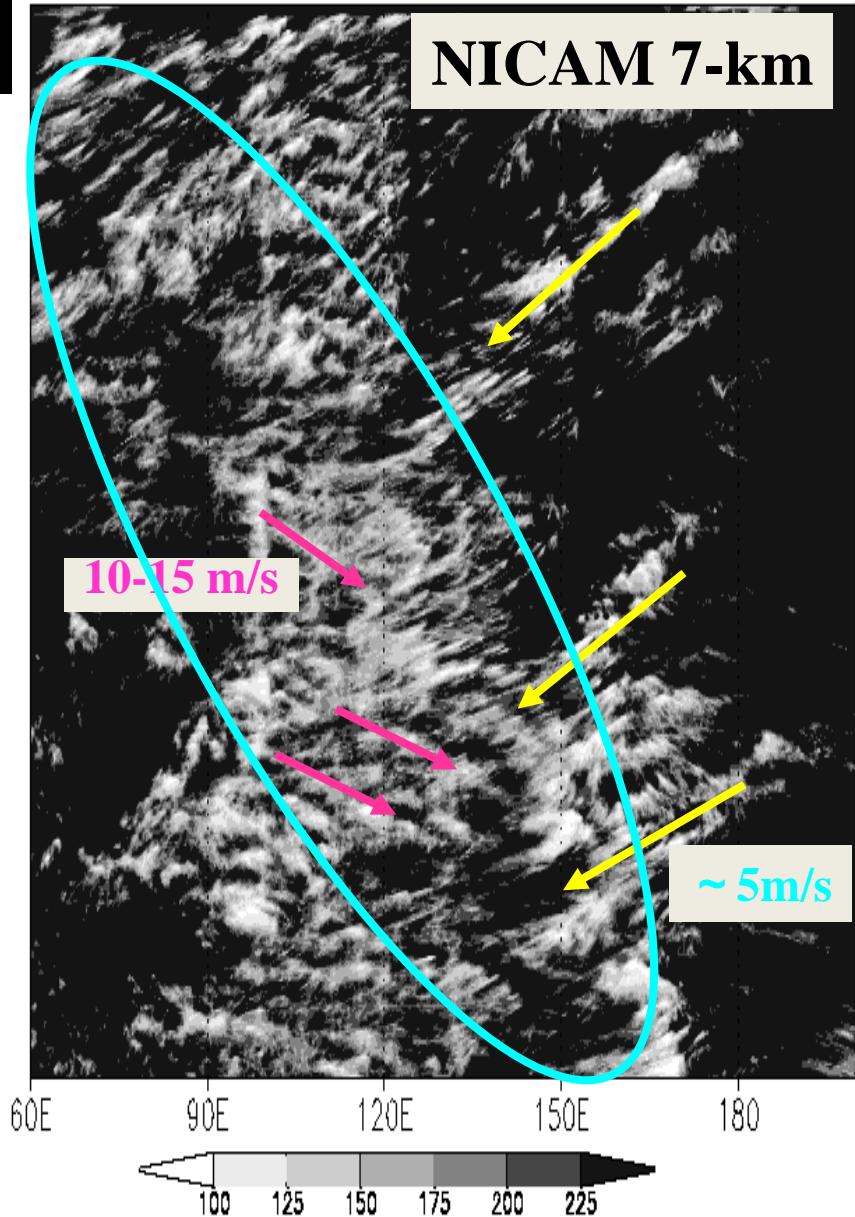
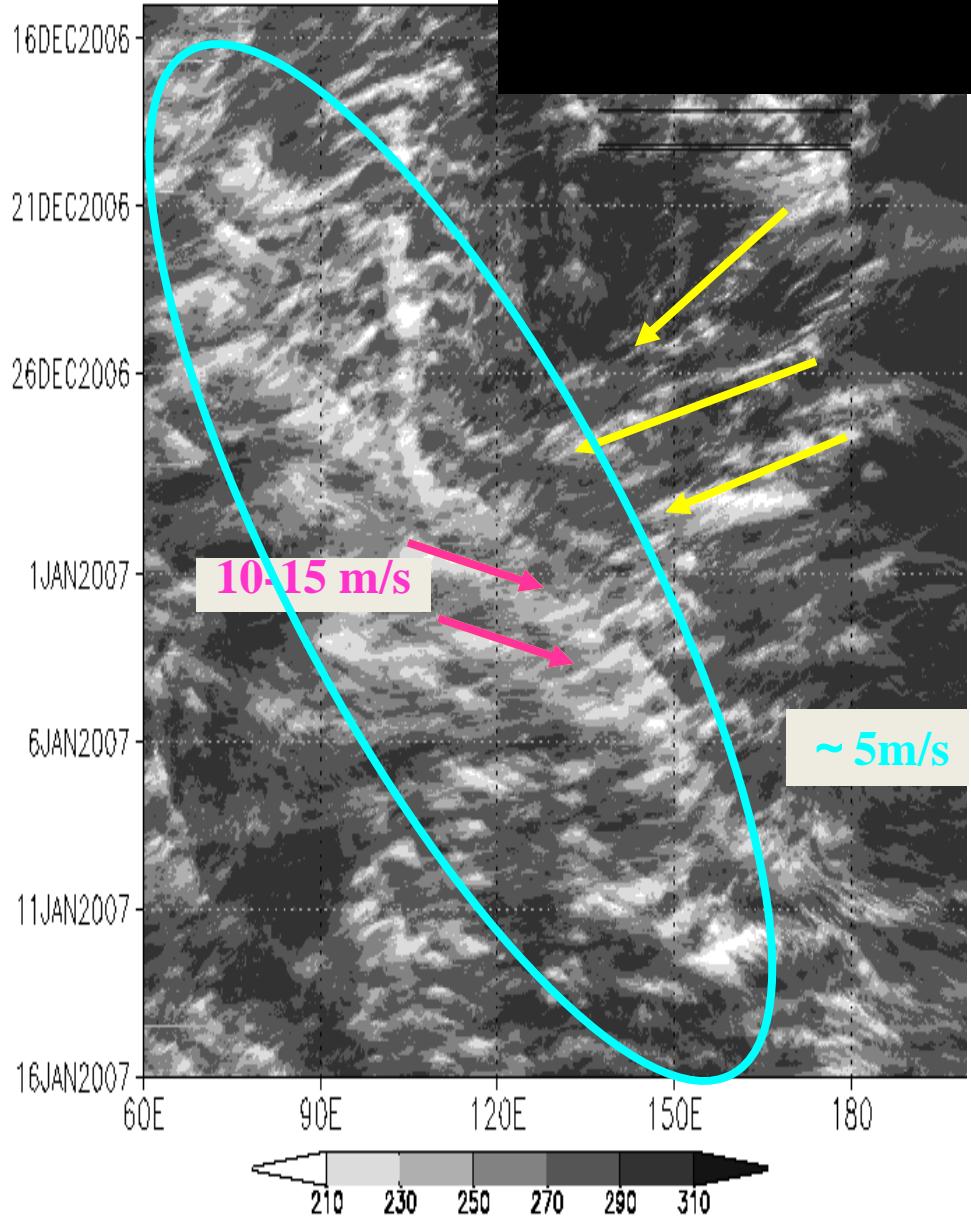
**Role of cold pools**

# Hovmöller diagrams: zonal winds & vertical cross section (composite)



# Internal structure of MJO Hovmöller diagrams: IR/OLR

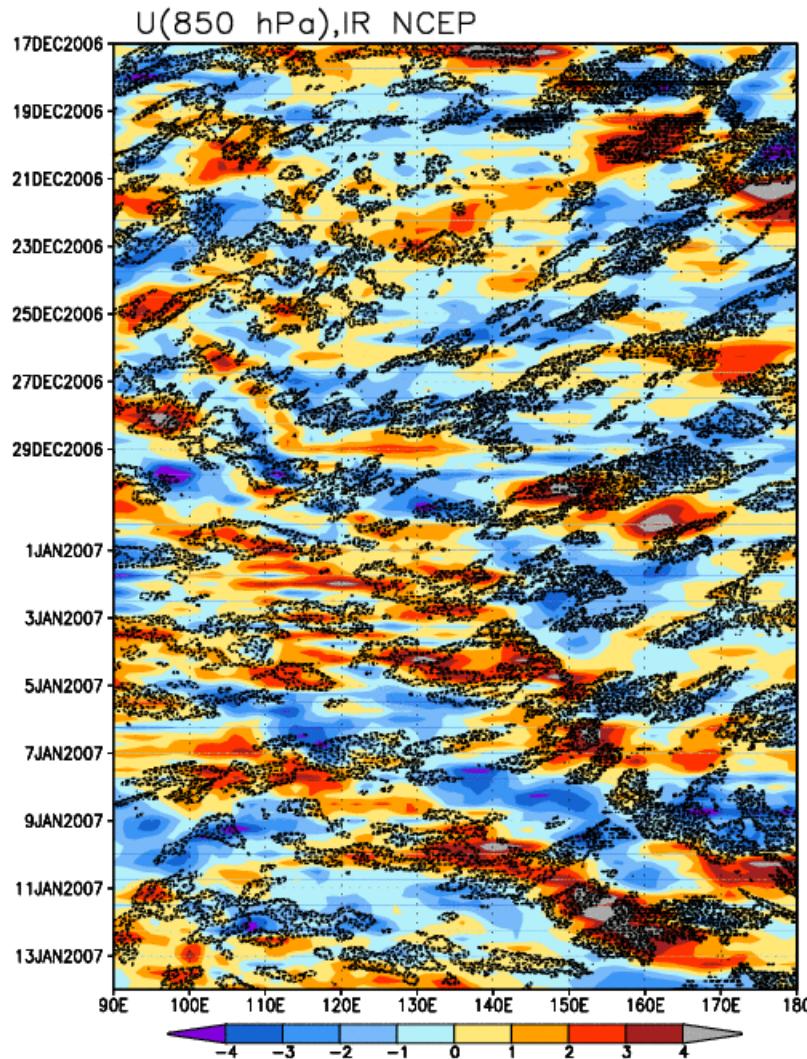
(Eq.)



Westward Rossby waves & Eastward Kelvin waves or squall type rain bands

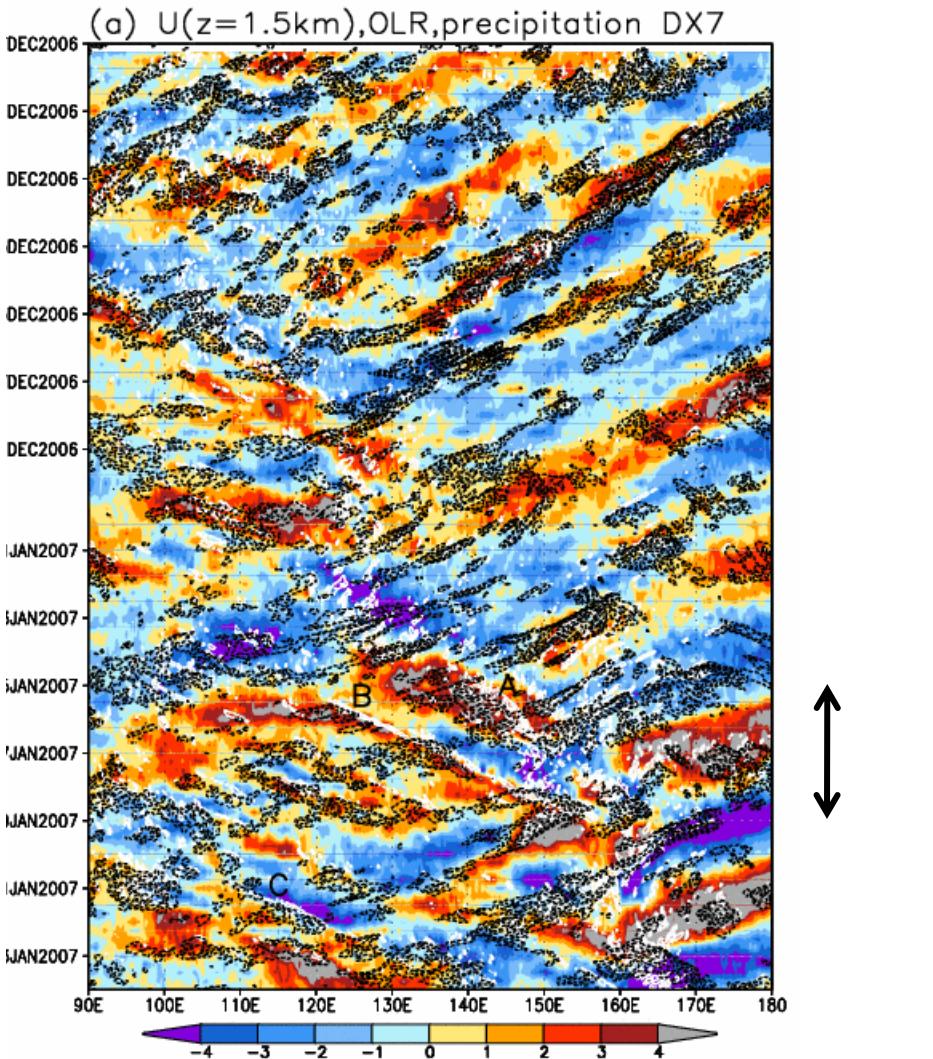
# Zonal wind (4-day running mean subtracted)

NCEP



Black lines: IR TBB

NICAM  $dx=7 \text{ km}$

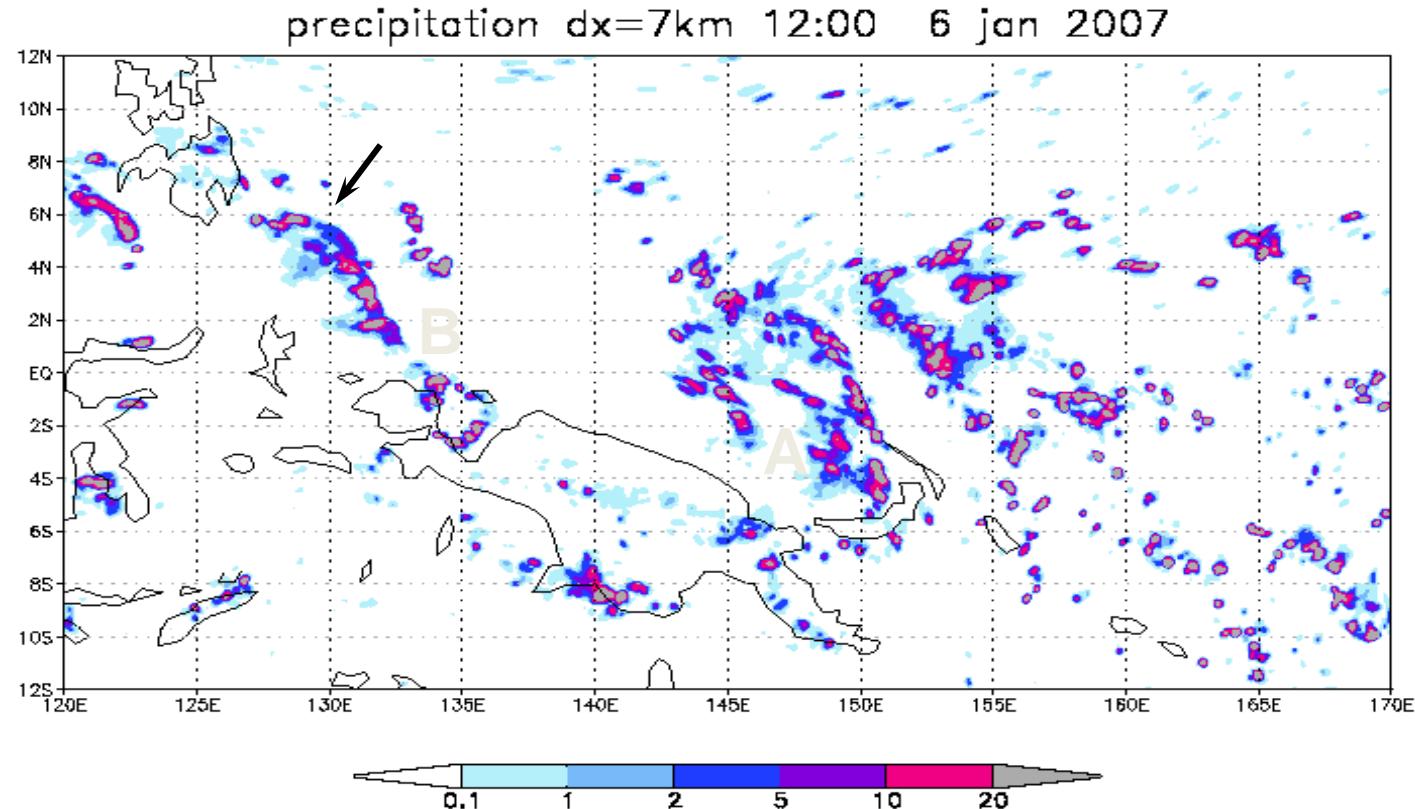


Black lines: OLR, white: precipitation

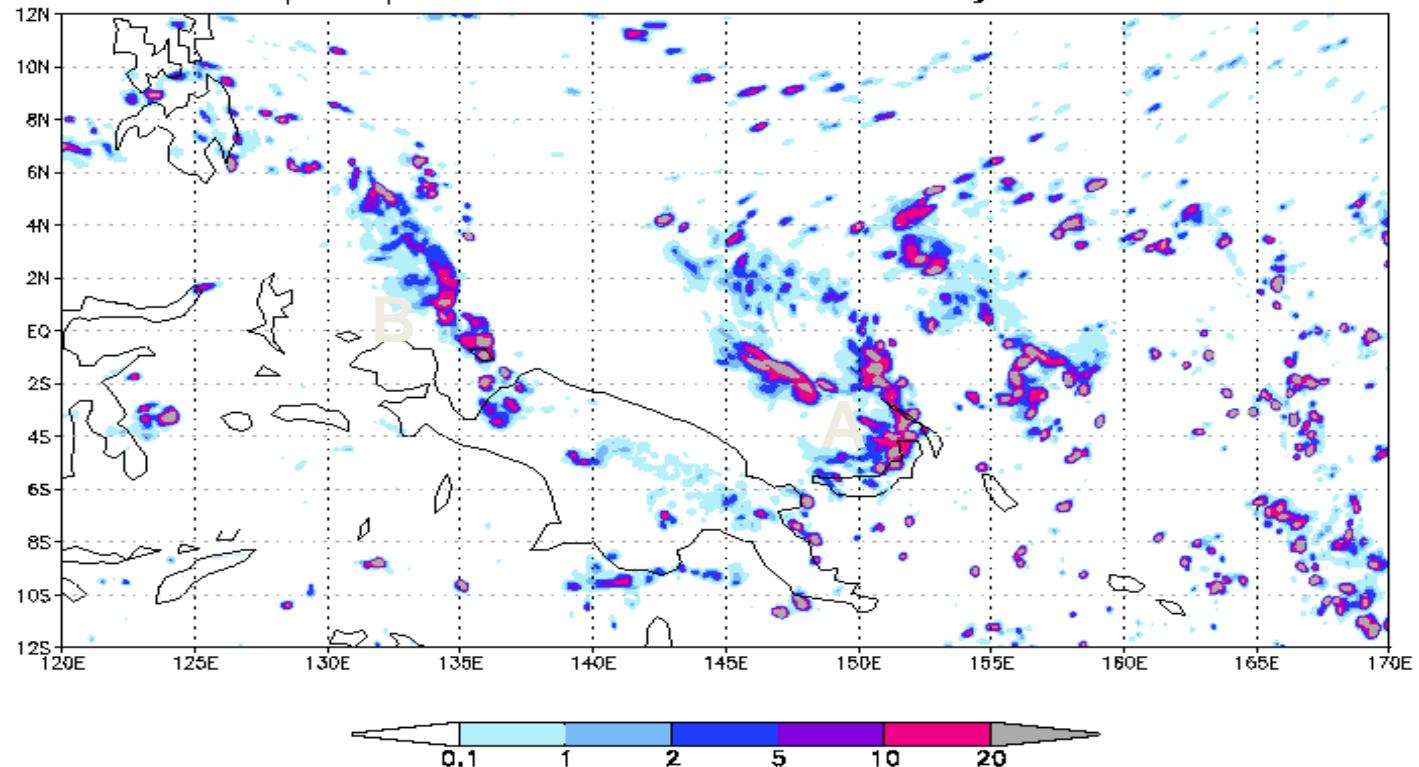


# NICAM (dx=7km)

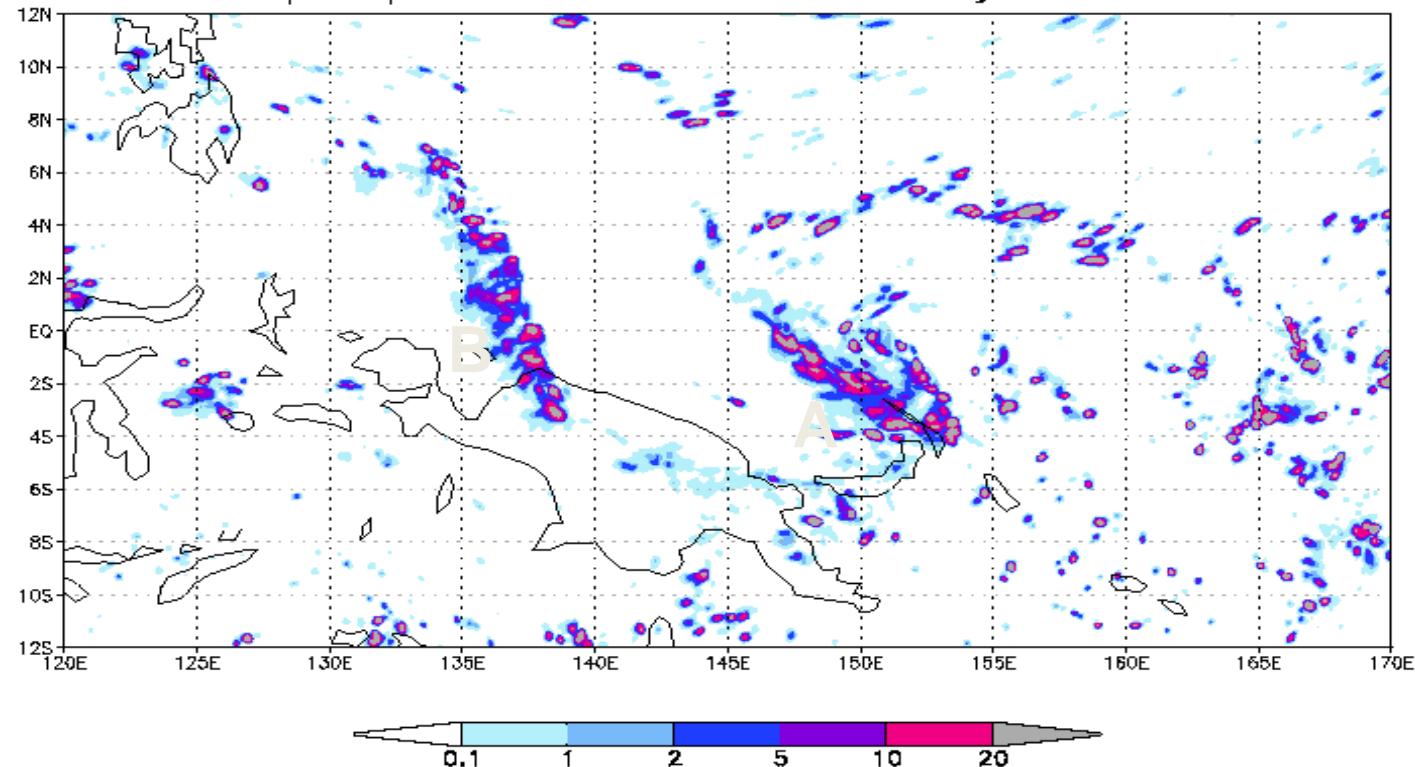
Similar feature in observations  
(Dr. H. Yamada)



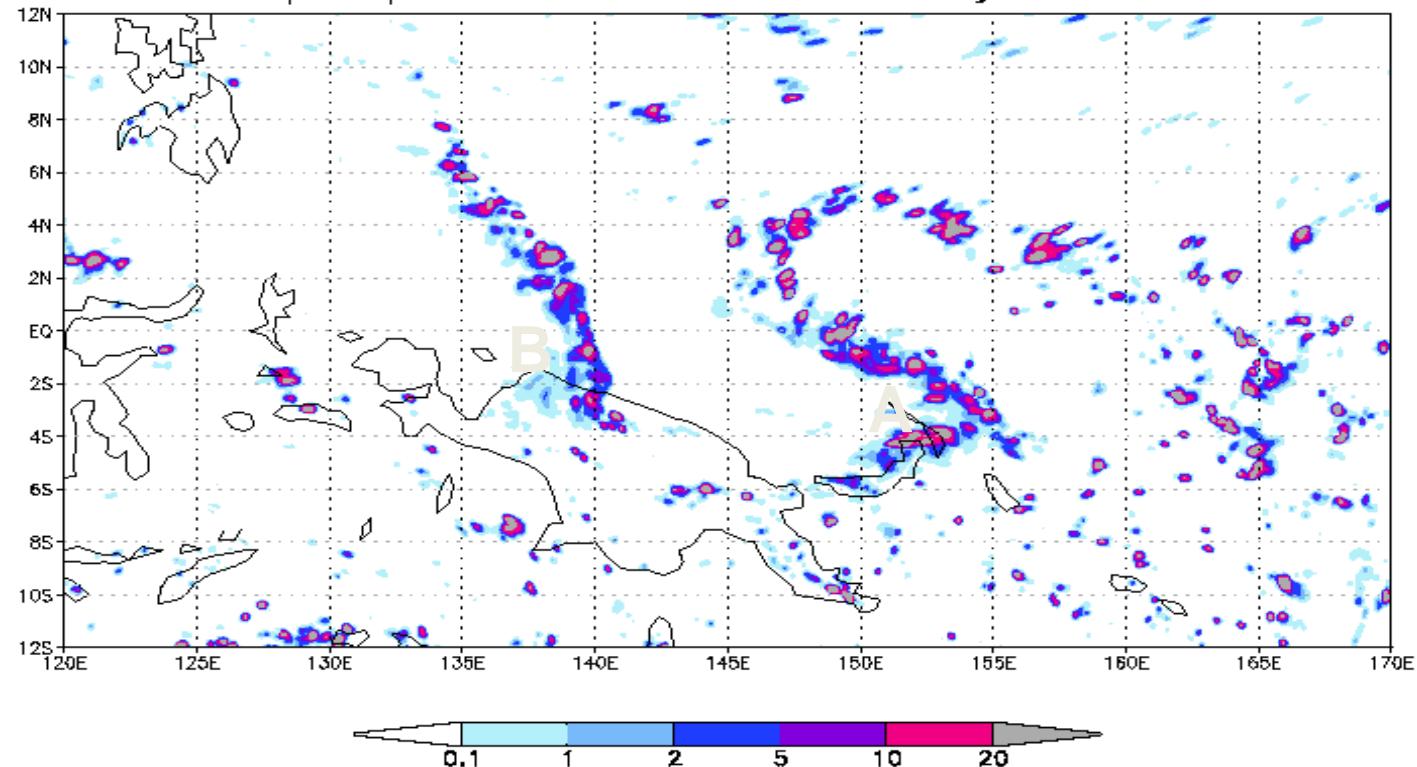
precipitation  $dx=7\text{km}$  18:00 6 jan 2007



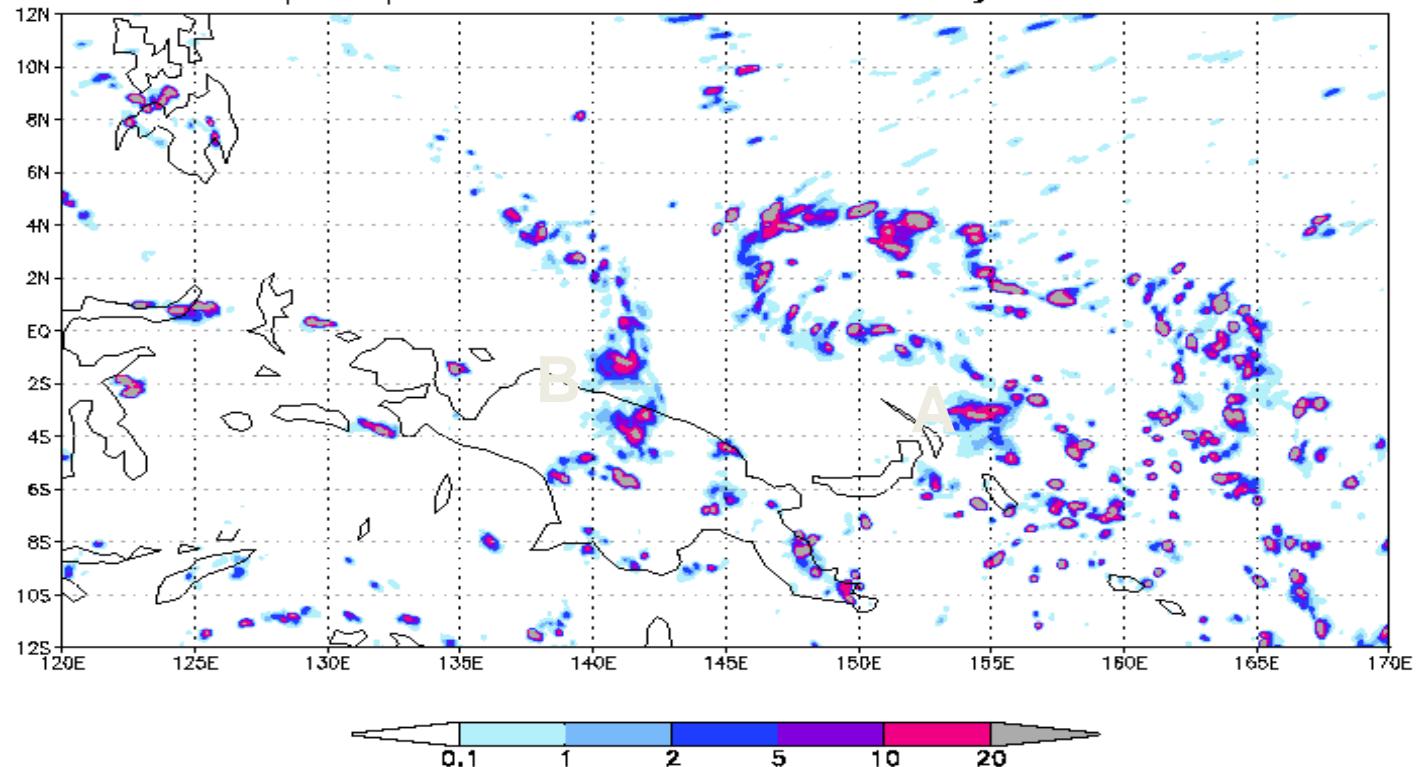
precipitation  $dx=7\text{km}$  00:00 7 jan 2007



precipitation  $dx=7\text{km}$  06:00 7 jan 2007



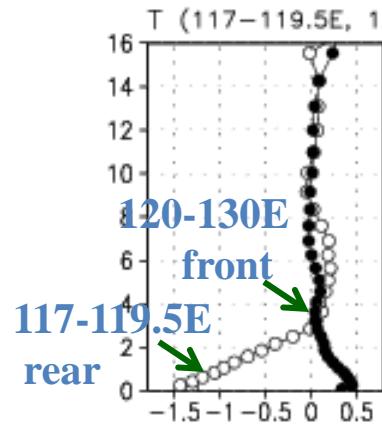
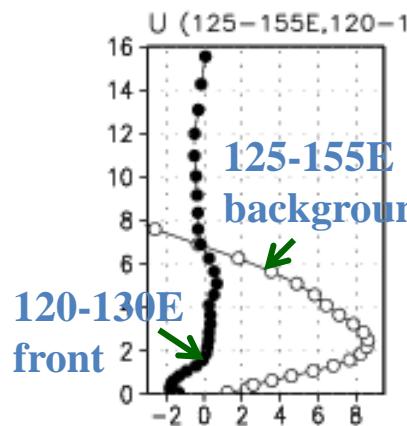
precipitation  $dx=7\text{km}$  12:00 7 jan 2007



# Vertical structure; composite along gust front

NICAM  
( $\text{dx}=7\text{km}$ )

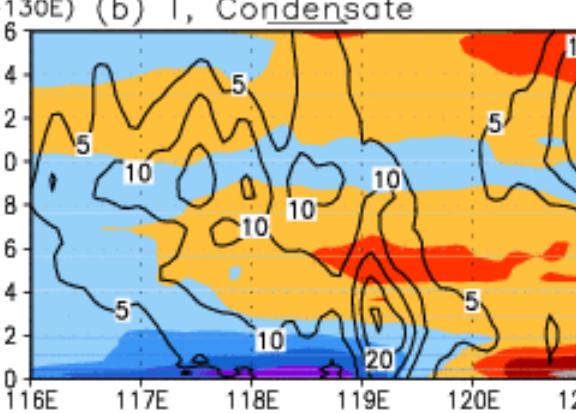
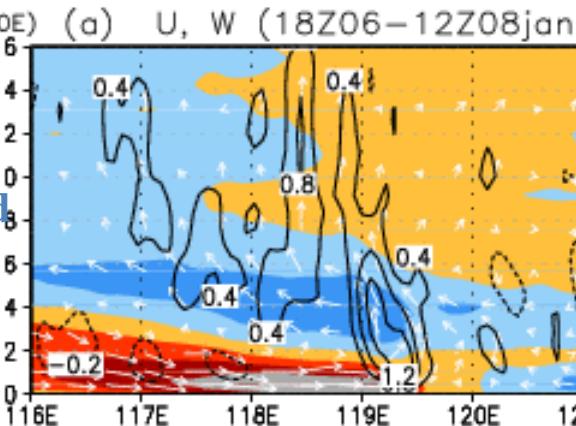
area-average



Rainband B

3N-3S average

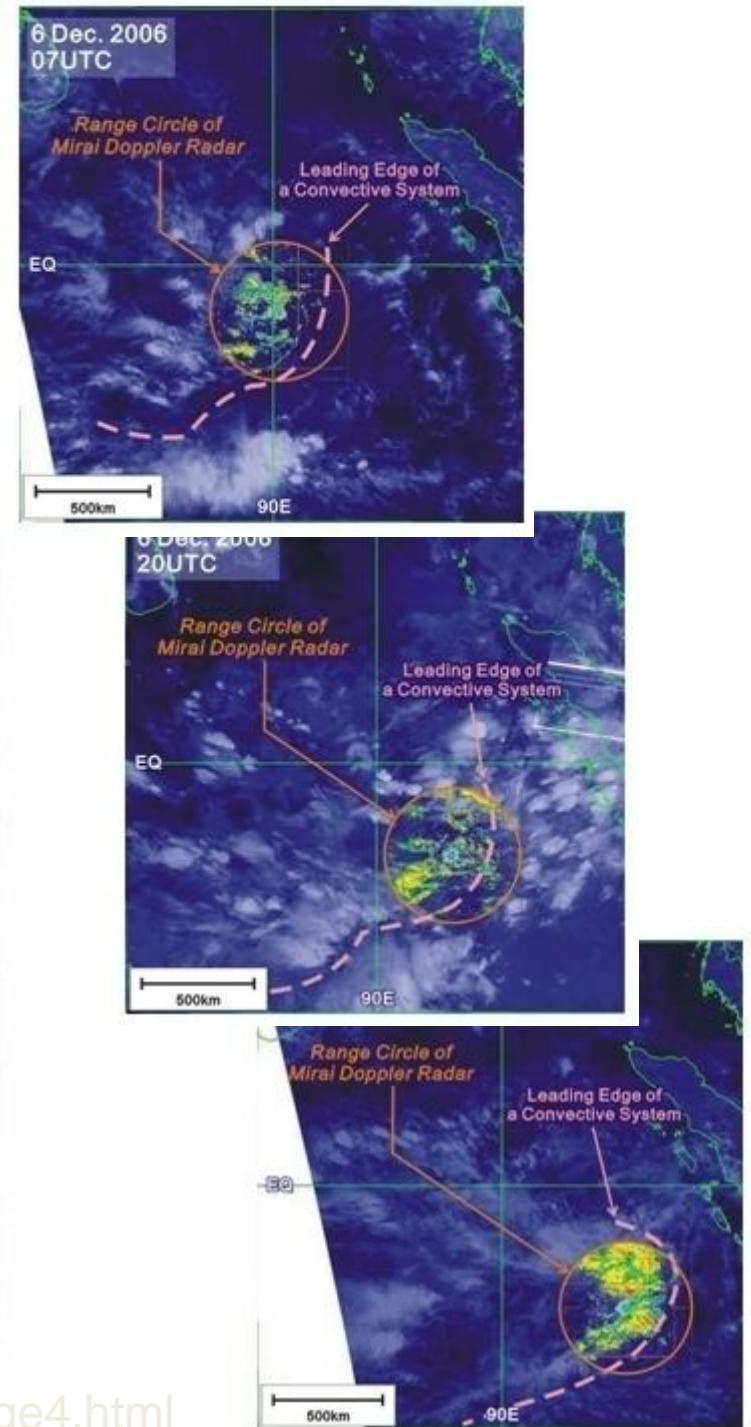
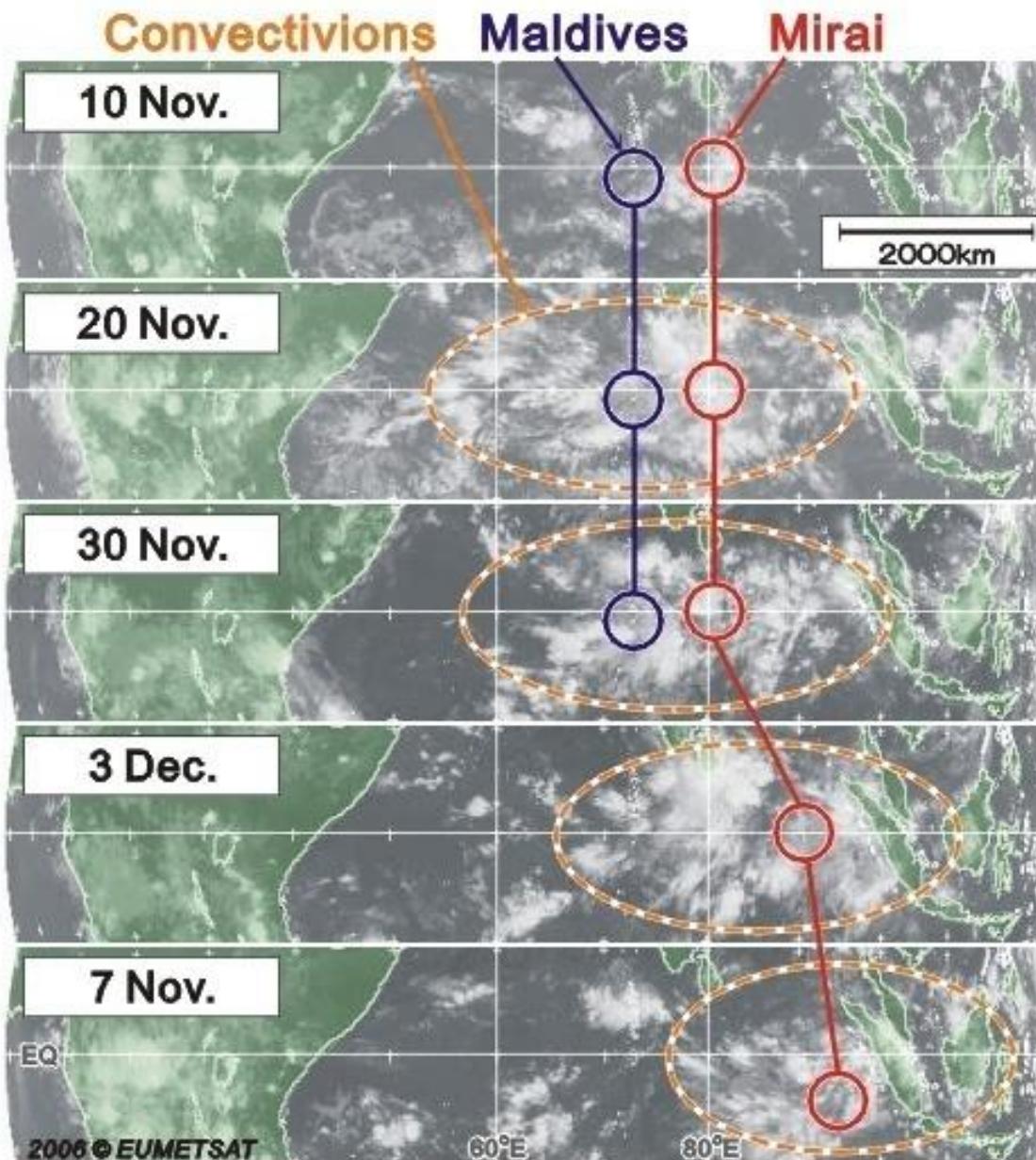
Zonal velocity  
contour:  
Vertical velocity



Temperature  
contour:  
Condensate

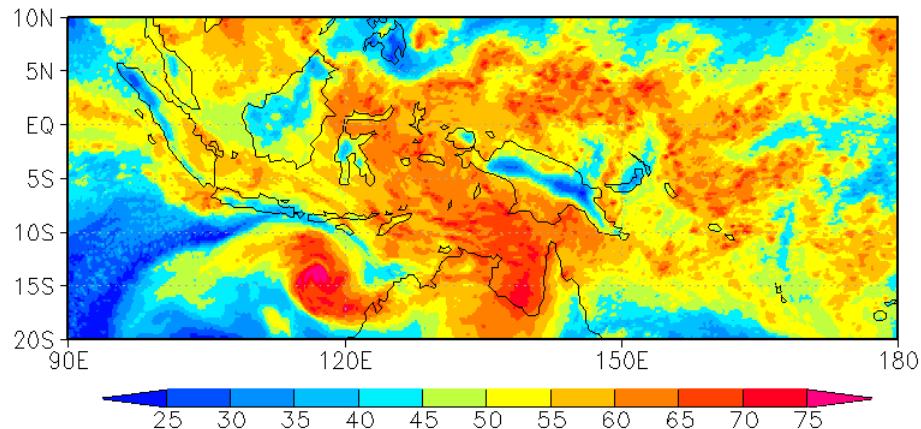
Squall-type cluster

# MISMO

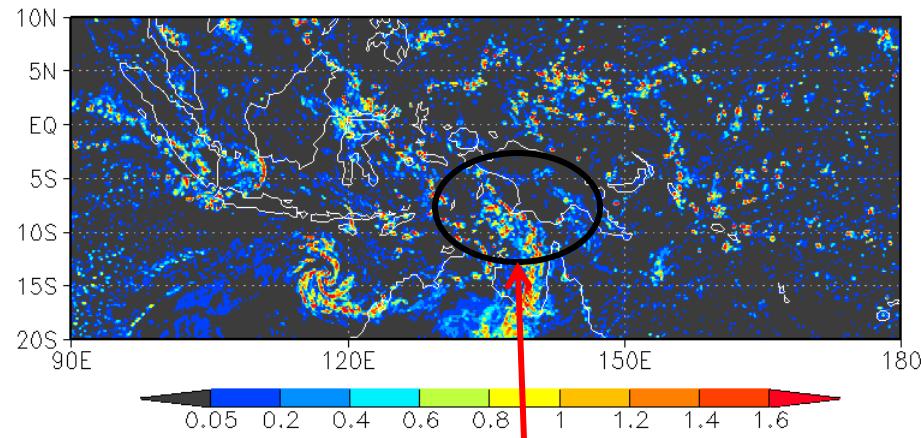


# Roles of squall line types clusters on MJO

## Precipitable water

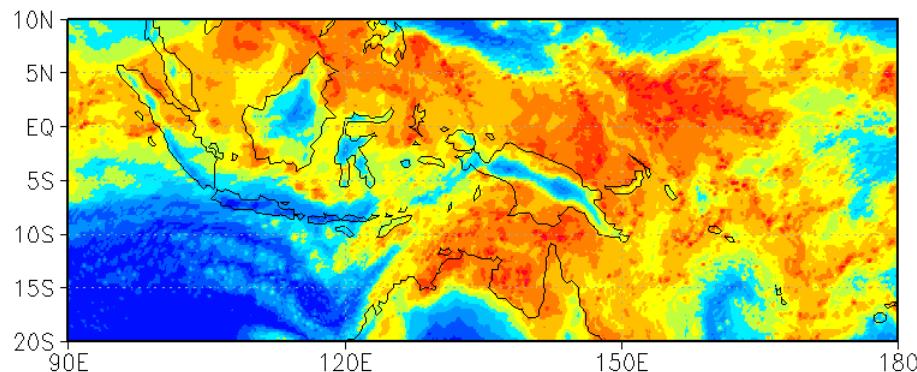


## Column integrated cloud water



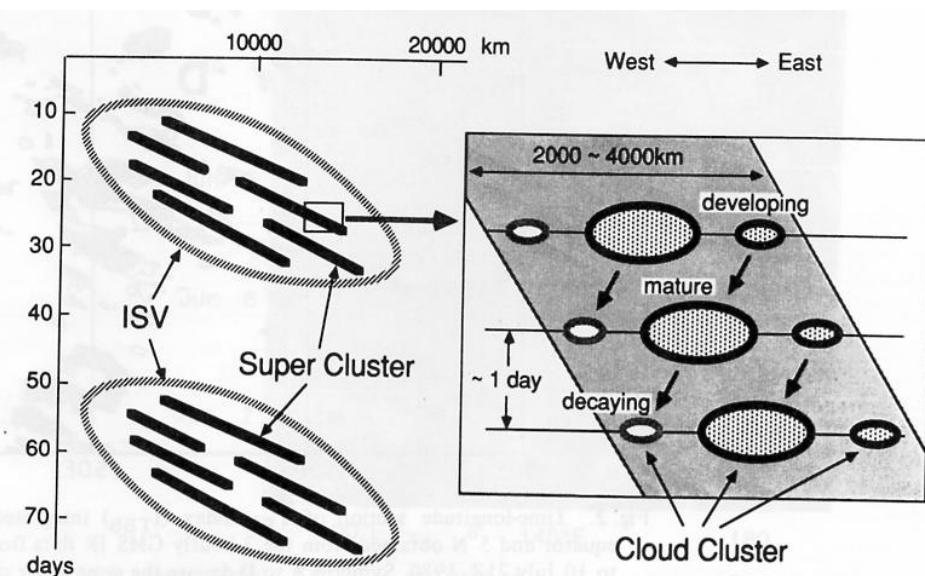
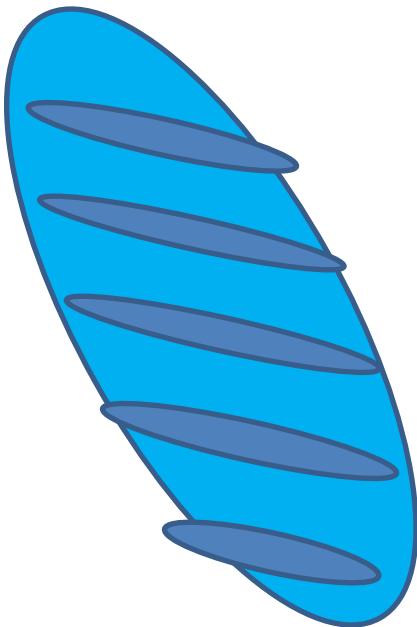
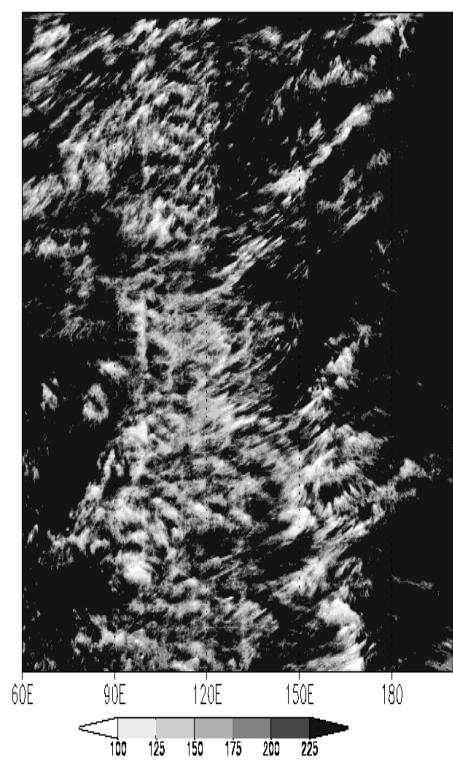
2Jan 2007

rainband



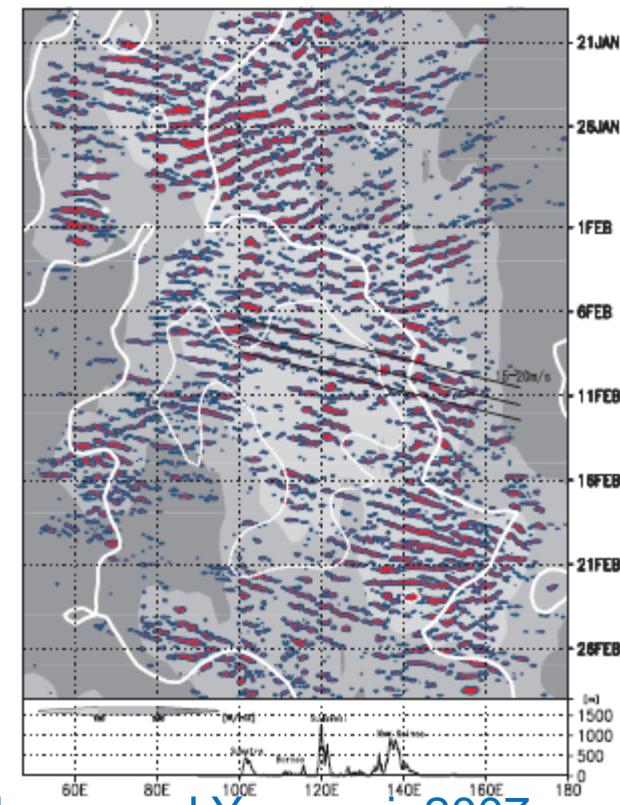
6 Jan 2007

Miura et al.(2007)



Nakazawa 1988

- Rossby waves: accumulation of water vapor on the front of MJOs. from eastward
- Moist Kelvin waves become active when MJOs are active.
- Multiscale interactions of Rossby/Kelvin waves and MJOs.



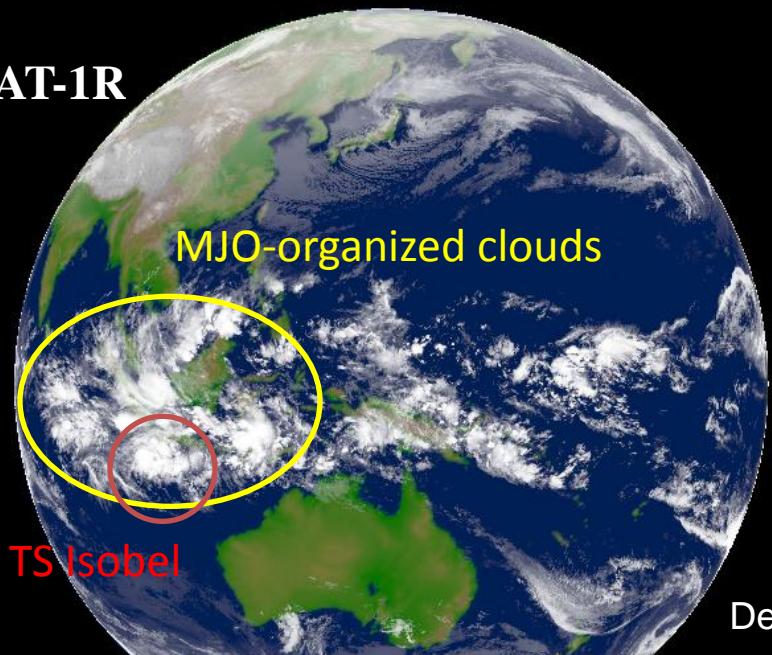
Ichikawa and Yasunari, 2007

# NICAM SIMULATIONS

- MJO simulations
- Tropical cyclones
- Monsoon simulations, ISVs and TCs
- Diurnal variability, cloud properties

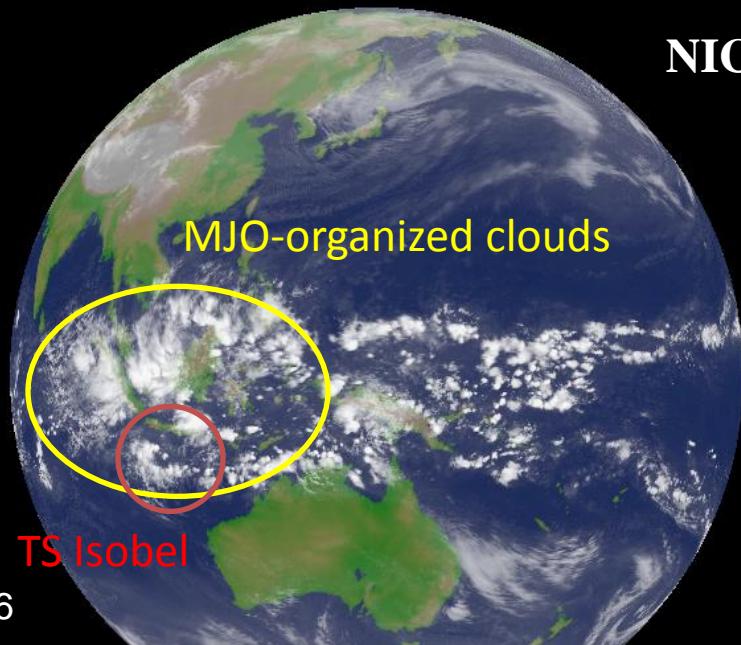
Fudeyasu, H., Wang, Y., Satoh, M., et al. (2008) The global cloud-resolving model NICAM successfully simulated the lifecycles of two real tropical cyclones. Geophys. Res. Lett., 35, L22808.

MTSAT-1R



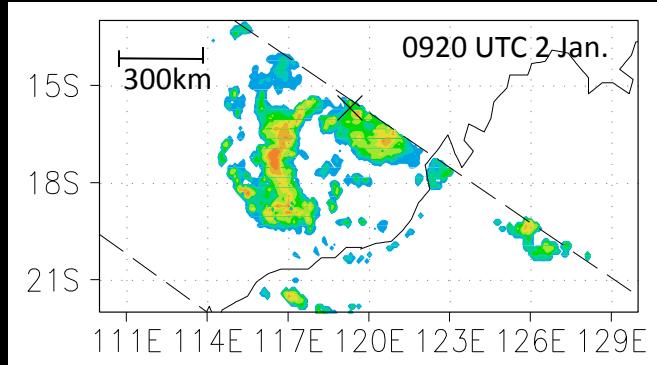
NICAM

Dec. 29 2006

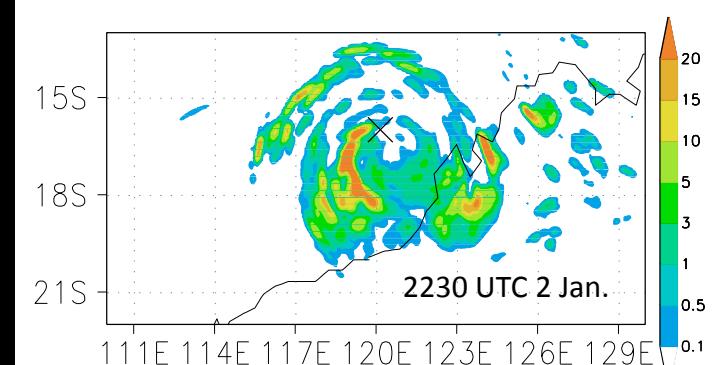


NICAM reasonably produced not only the large-scale circulation, such as the MJO, but also the embedded mesoscale features, such as TC rainbands.

Surface rain rate ( $\text{mm hour}^{-1}$ ) by TRMM-TMI

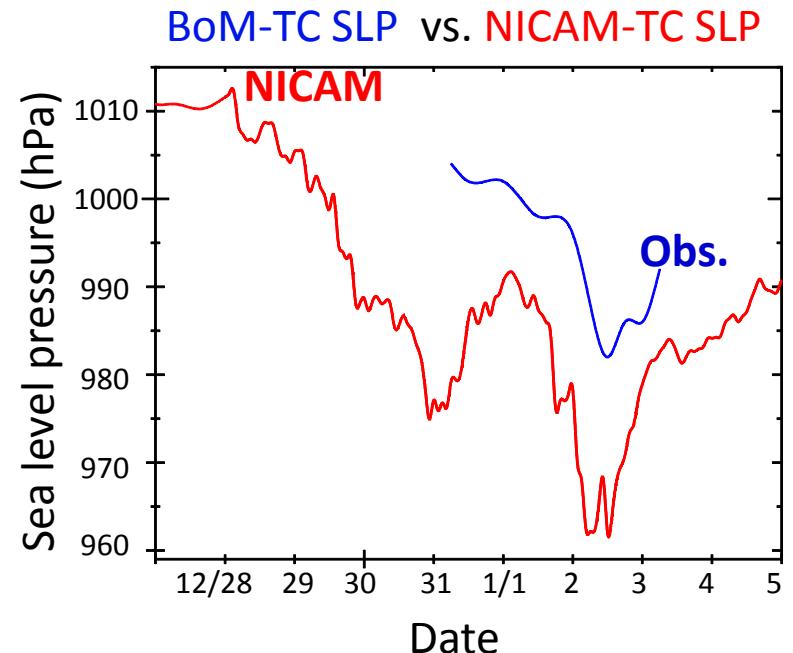
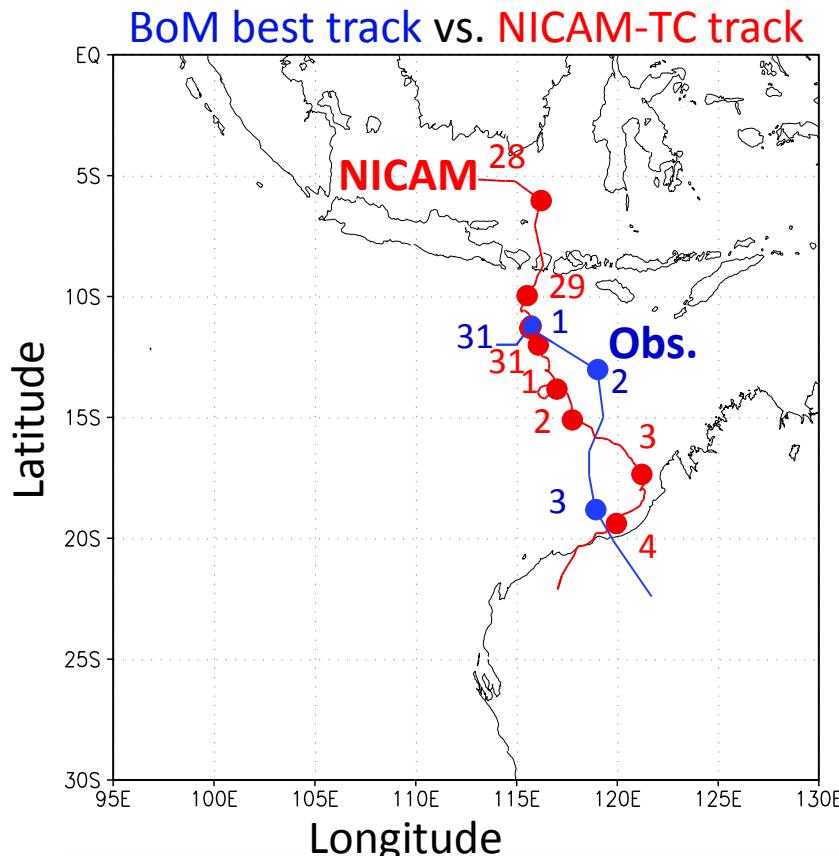


Surface rain rate ( $\text{mm hour}^{-1}$ ) by NICAM



# Observation vs. NICAM

BoM: Australian Government Bureau of Meteorology

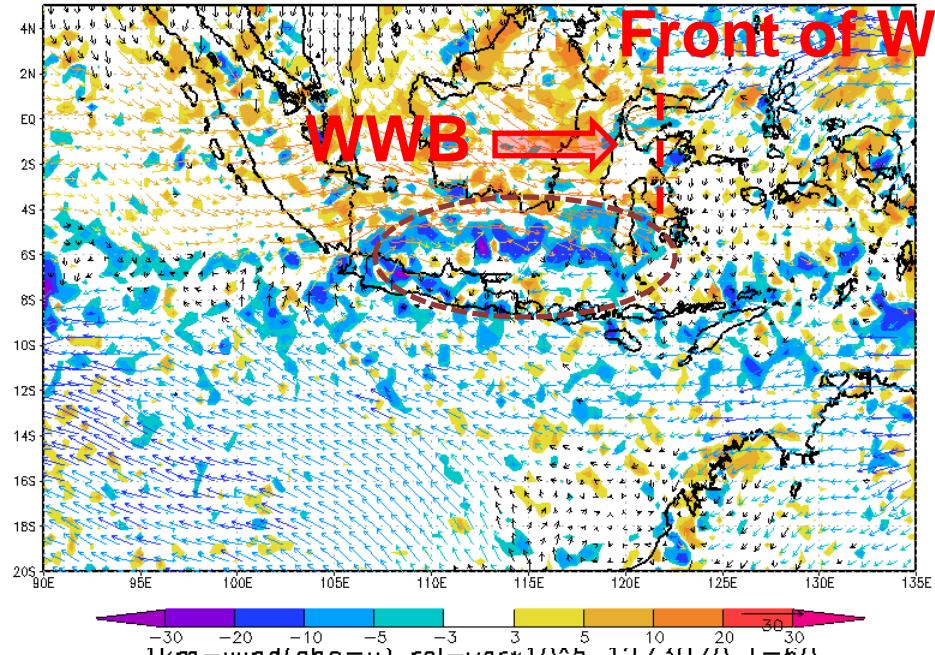


NICAM reasonably captured Isobel's motions, timing, and intensity changes.

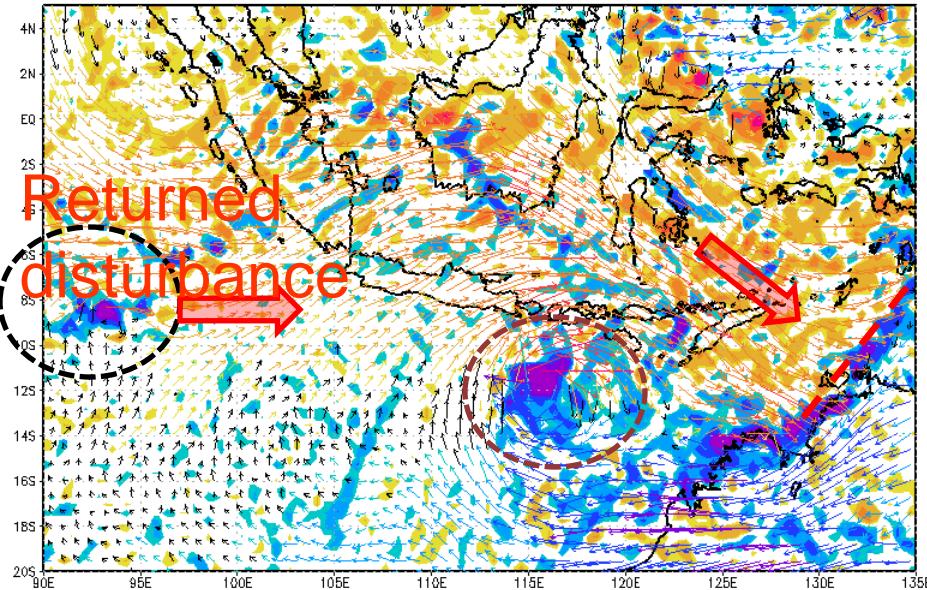
Fudeyasu et al. (2008, GRL)

# TC genesis in MJO

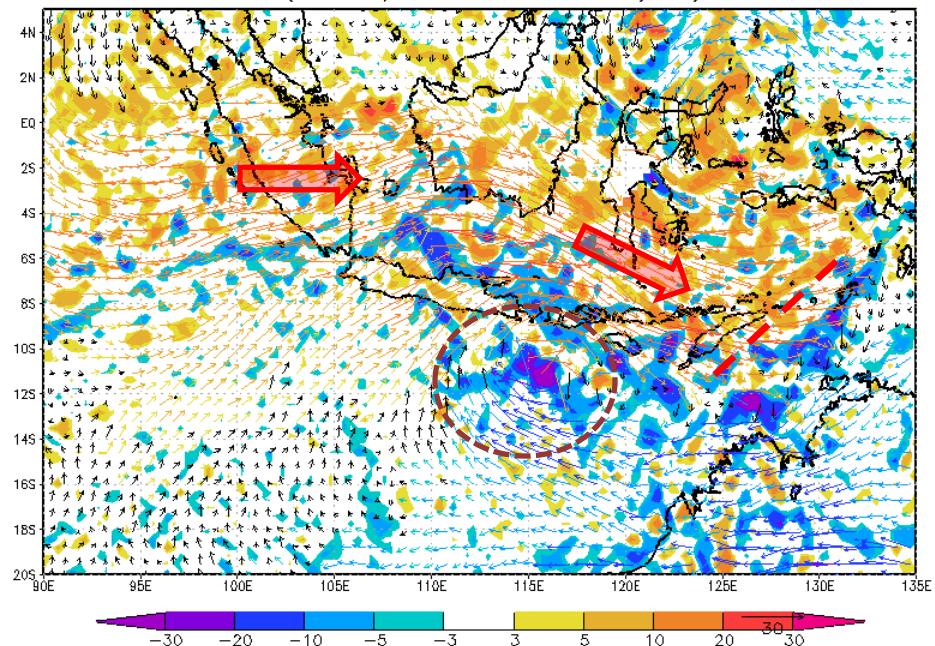
1km-wind(sh=0) rel-vor\*10^5 12/27/12 T=50



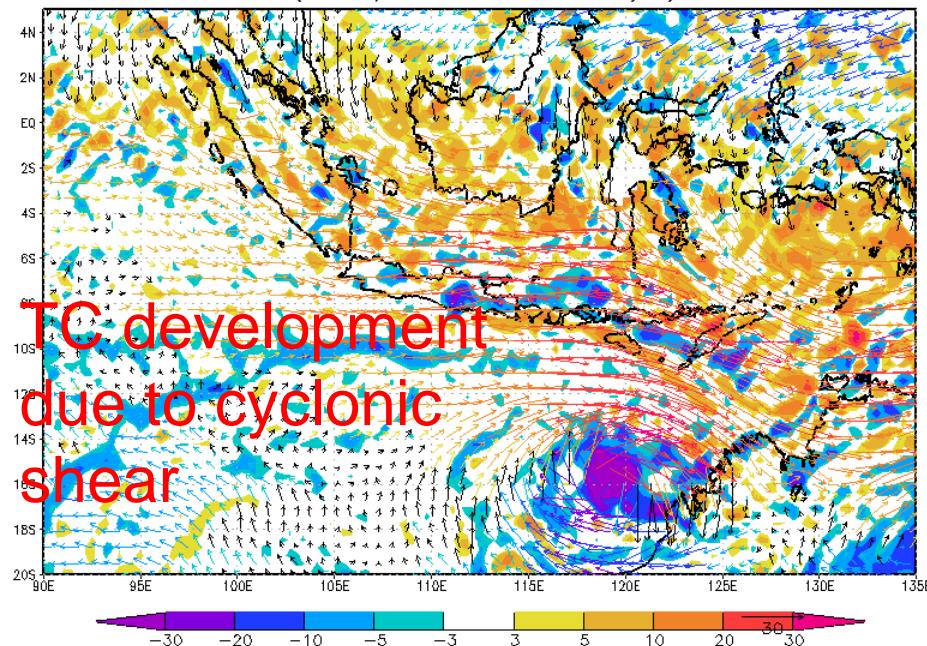
1km-wind(sh=0) rel-vor\*10^5 12/31/0 T=64

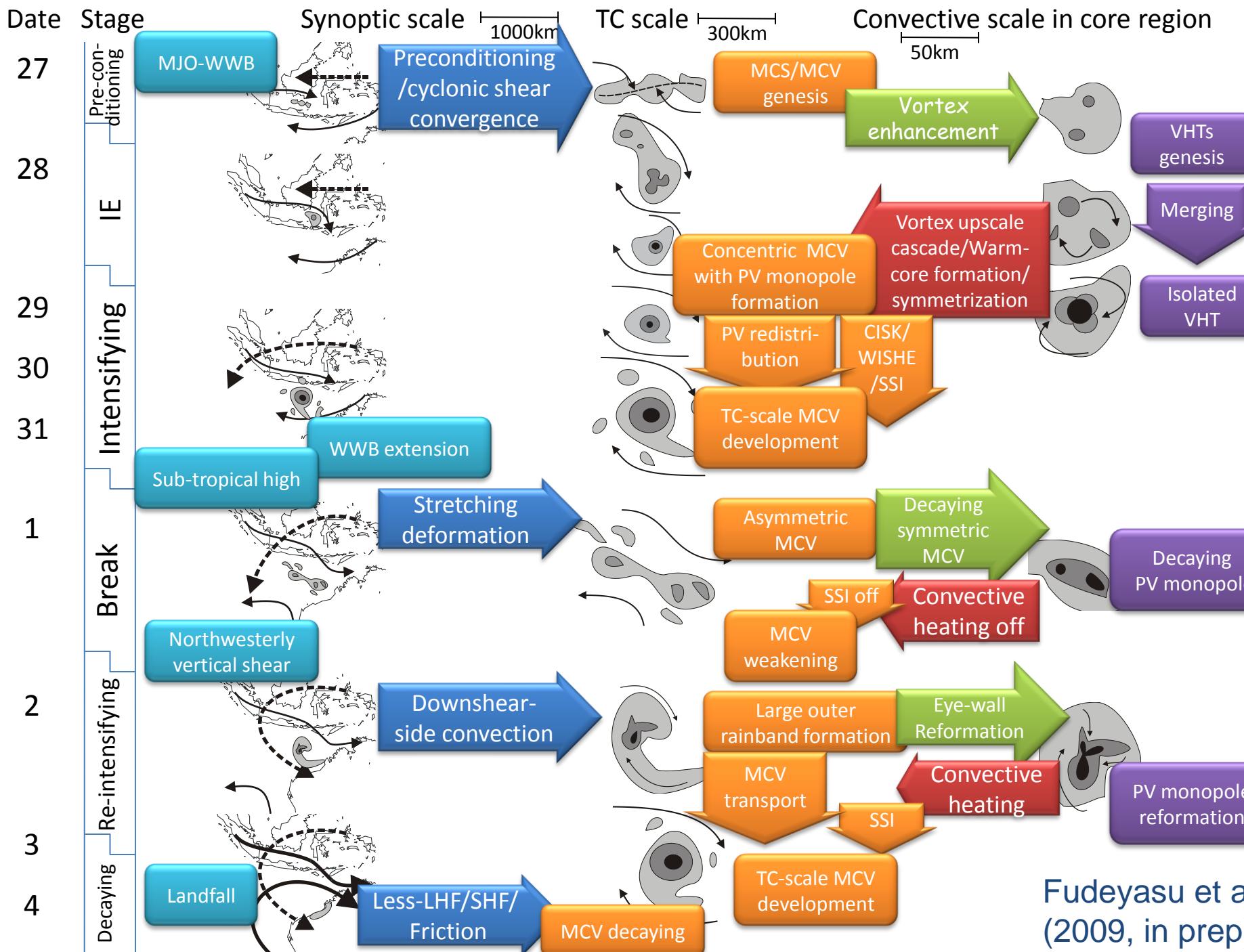


1km-wind(sh=0) rel-vor\*10^5 12/30/0 T=60



1km-wind(sh=0) rel-vor\*10^5 01/2/12 T=74





# NICAM SIMULATIONS

- MJO simulations
- Tropical cyclones
- **Monsoon simulations, ISVs and TCs**
- Diurnal variability, cloud properties

# Monsoon simulations

Oouchi et al. (2009) Asian summer monsoon simulated by a global cloud-system resolving model: Diurnal to intra-seasonal variability. *Geophys. Res. Lett.*, 36, L11815.

Oouchi et al. (2009) A simulated preconditioning of typhoon genesis controlled by a boreal summer Madden-Julian Oscillation event in a global cloud-resolving mode. *SOLA*, 2009, Vol. 5, 065.068, doi:10.2151/sola.2009.017.

- Boreal Summer experiments:
  - 14km: June-Oct. 2006
  - 7km: June-Aug. 2006

# Precipitation distribution over south Asia average, June-Aug., 2004

TRMM observation

NICAM 7km-grid exp.

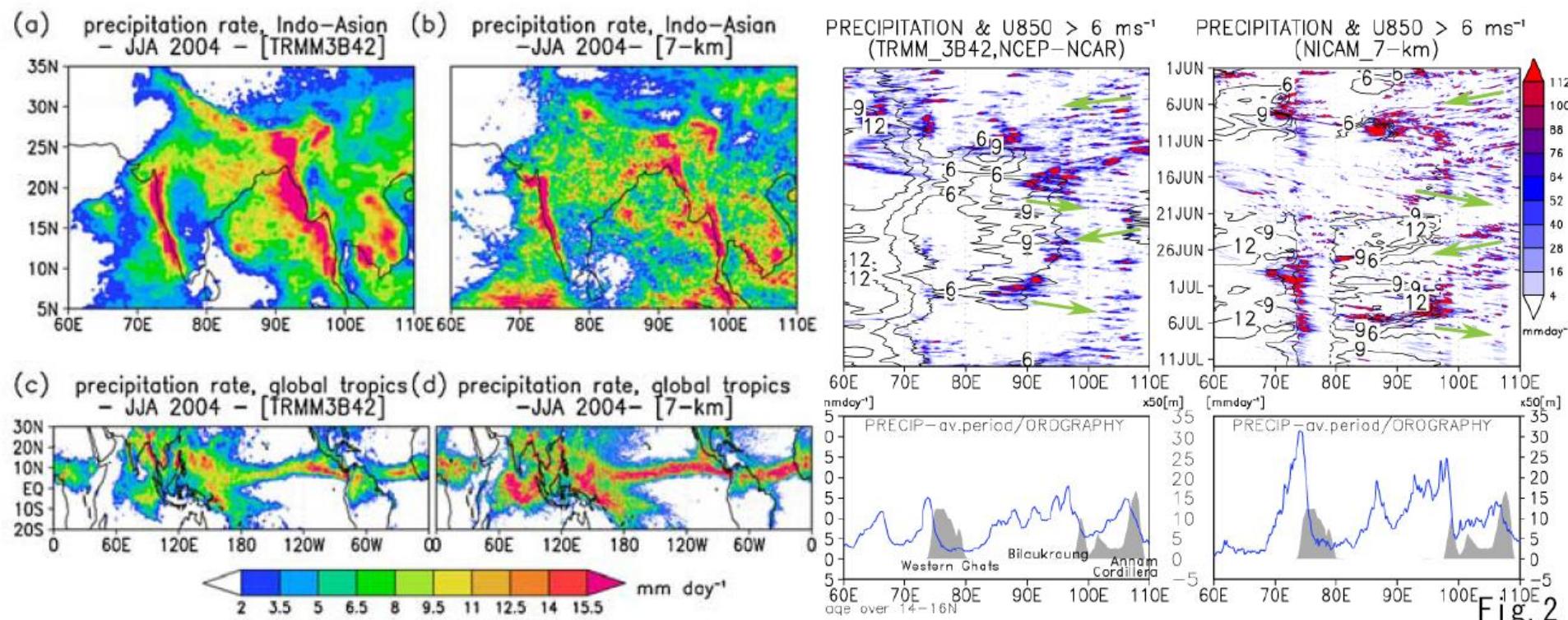
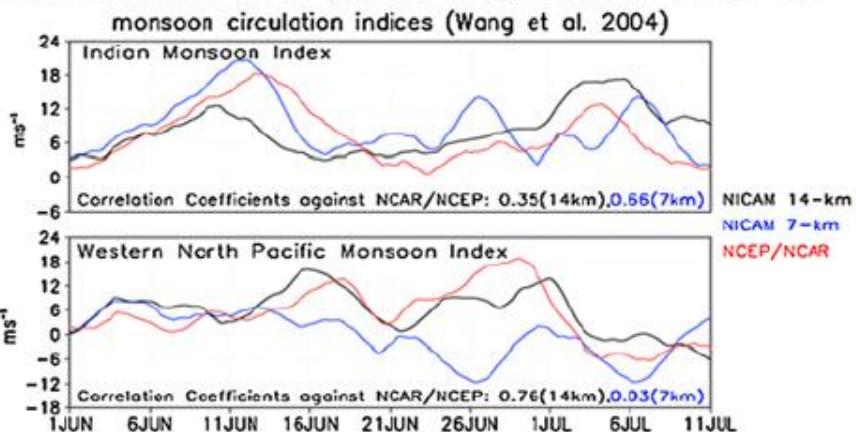
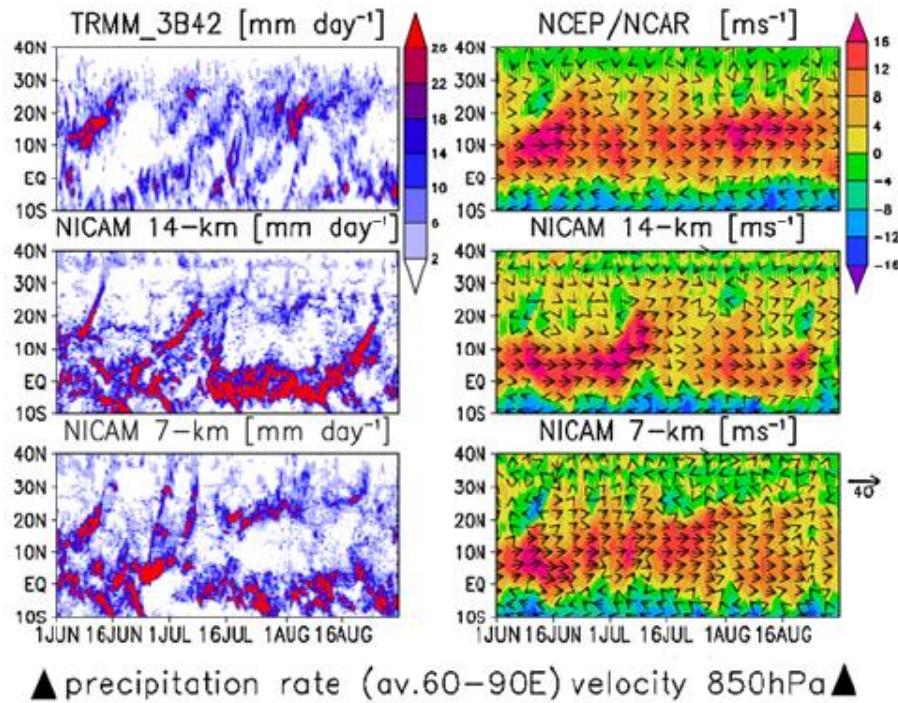


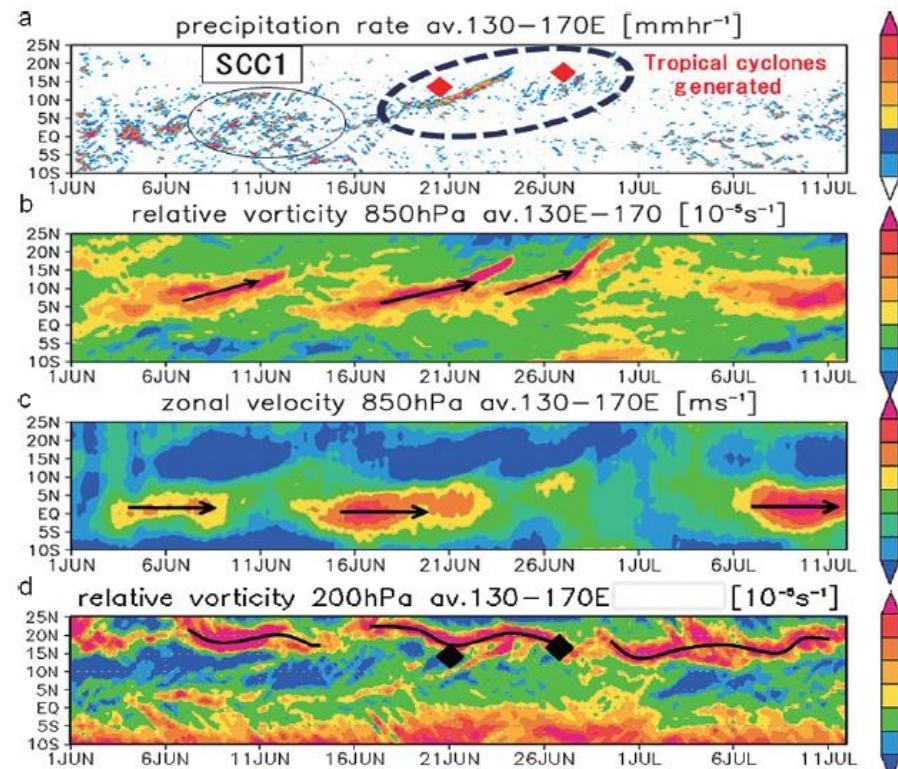
Fig. 2

# Intra-Seasonal variabilities

Indian Ocean



Western Pacific



- Northward propagation in the Indian Ocean
- Monsoon index
- Boreal summer MJOs and TC activities

Ouchi et al. (2009, SOLA)

# The Myanmar cyclone simulations

Taniguchi, et al. (2009) Ensemble simulation of cyclone Nargis by a Global Cloud-system-resolving Model - modulation of cyclogenesis by the Madden-Julian Oscillation. J. Meteor. Soc., submitted.

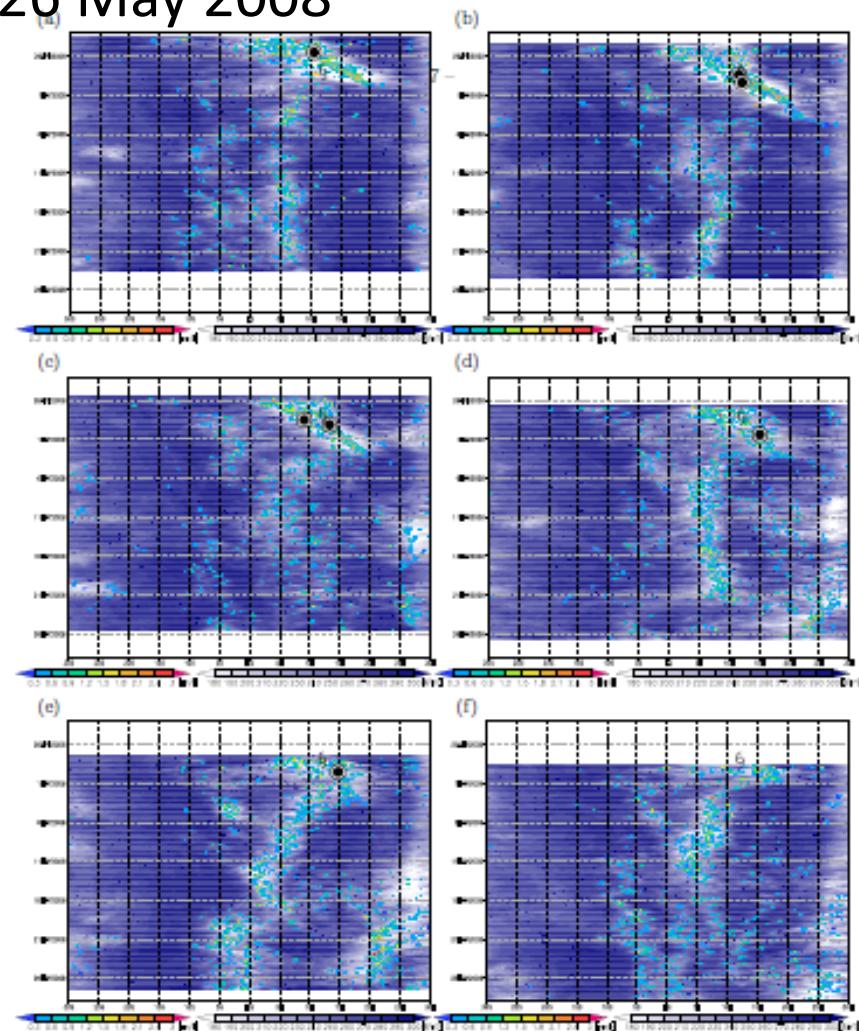
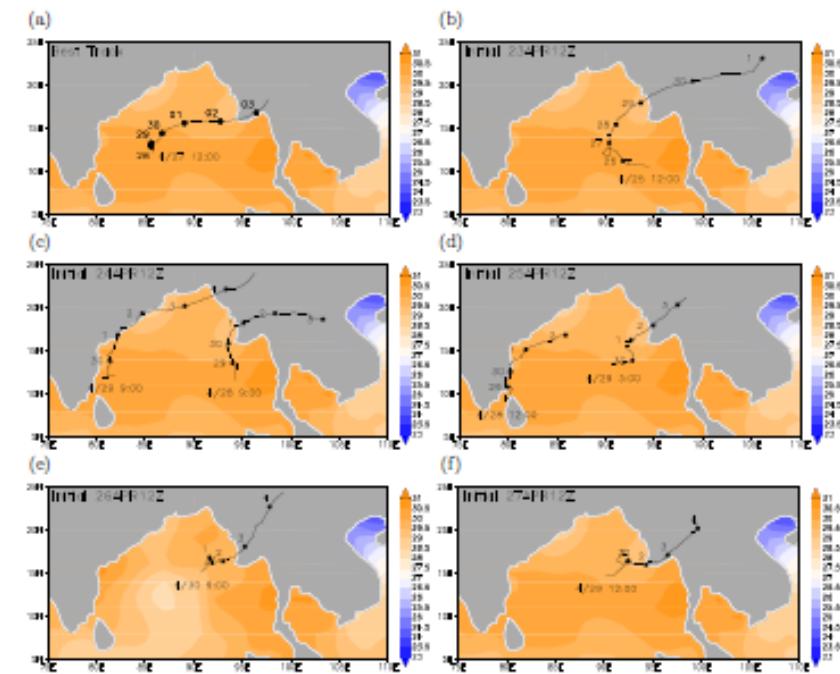
Yanase et al. (2009) Environmental modulation and numerical predictability associated with the genesis of tropical cyclone Nargis (2008). J. Meteor. Soc., submitted.

- The Myanmar cyclone Nargis
  - 14km: Apr. 2008, Ensembles
  - Regional NICAM exp.

# Myanmar cyclone Nargis (2008) ensemble simulations

## TC genesis captured with ISV and MJO

### 26 Apr. – 26 May 2008

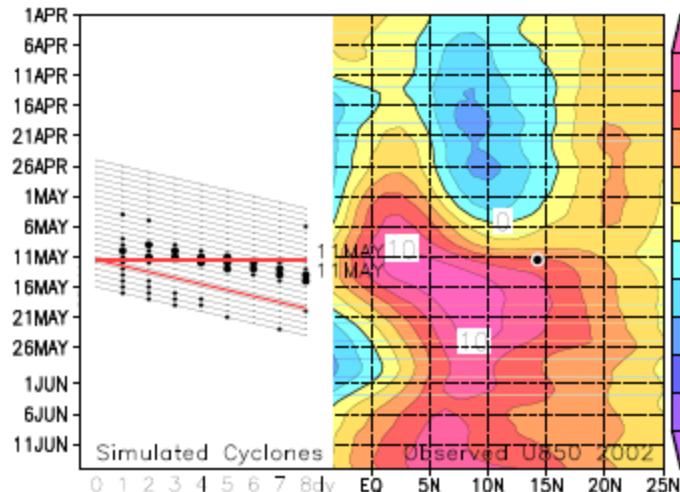


Taniguchi et al. (2009, JMSJ, submitted)

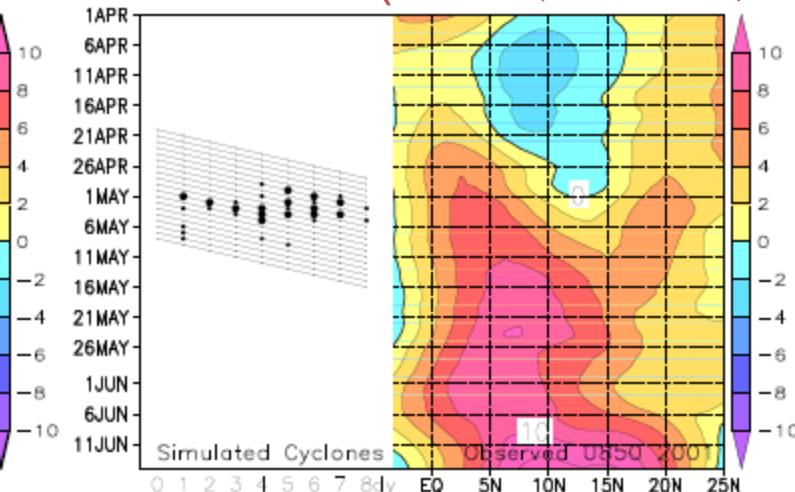
# TC cyclogenesis in Indian Ocean is generally captured with ISV using stretch-NICAM

Yanase et al. (2009, JMSJ, submittd)

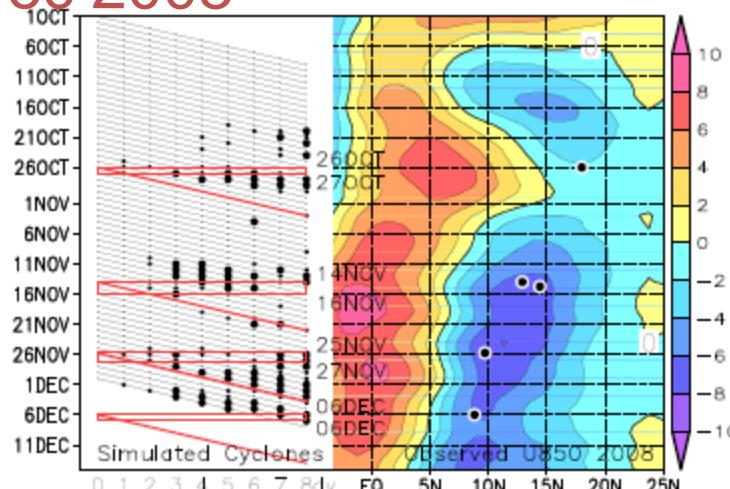
(a) 2002



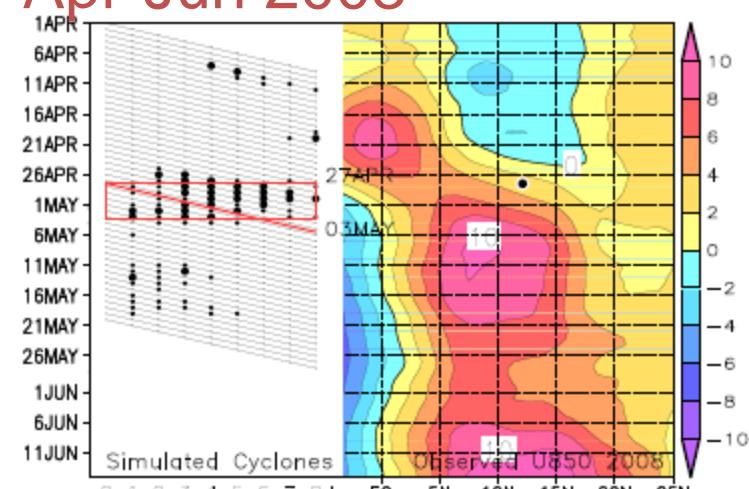
(b) 2004



Oct-Dec 2008

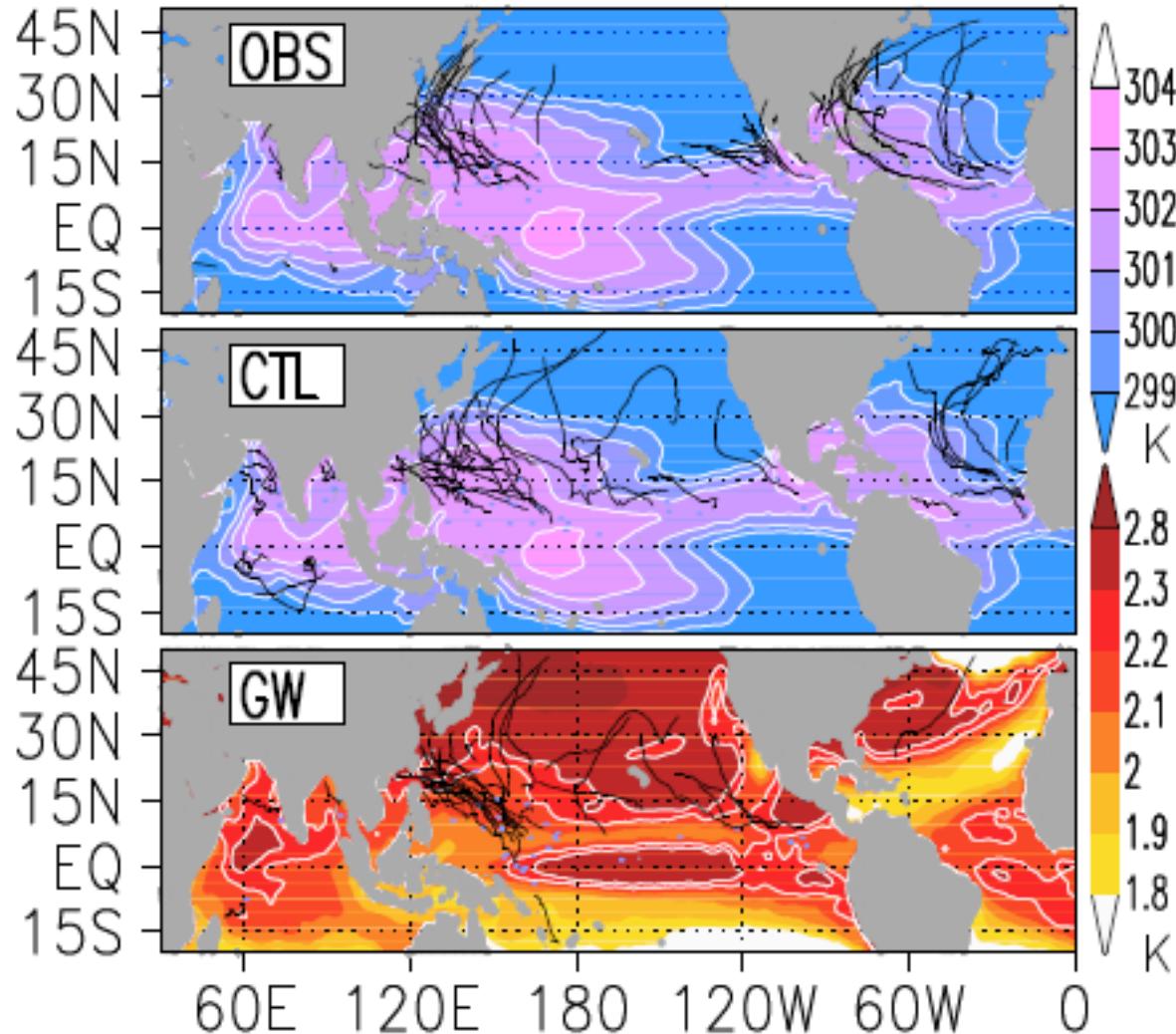


Apr-Jun 2008



# Number and intensities of tropical cyclones

Yamada et al.(2009, in prep.) & K. Oouchi's talk on Tuesday



- TC threshold 17m/s
- TC activities with ISVs, easterly

# Change in Tropical cyclone intensities

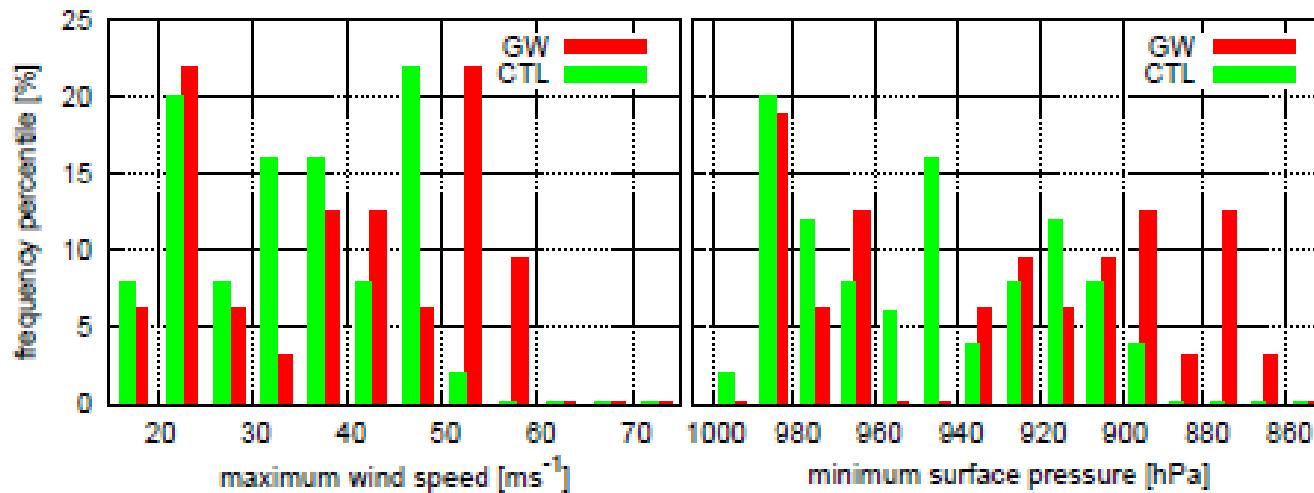


Figure 3.

CTL : JJA, 2004

GW: JJA, average of 2070-99

**Consistent with other studies:  
less number and stronger TCs**

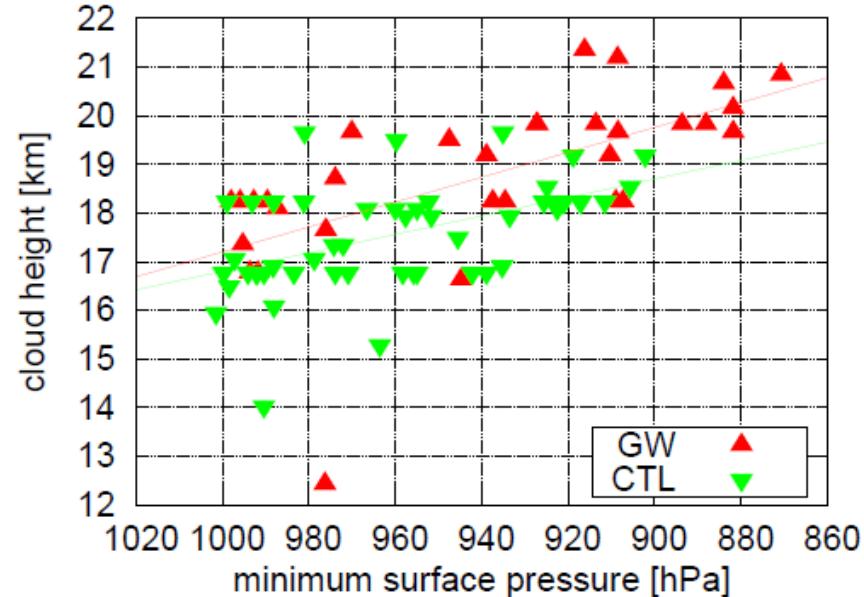


Figure 4.

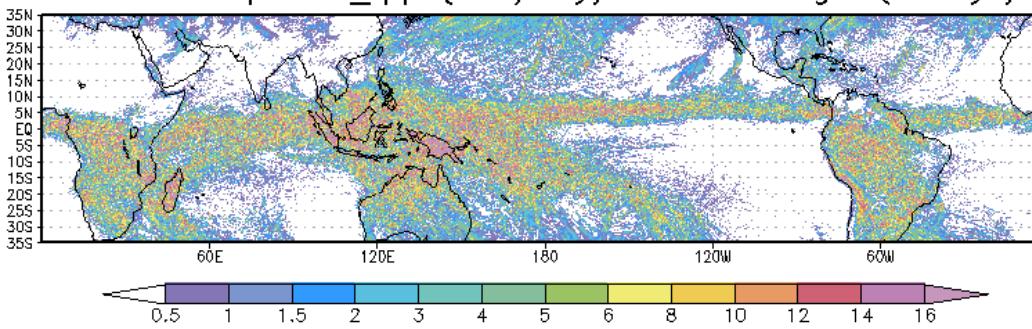
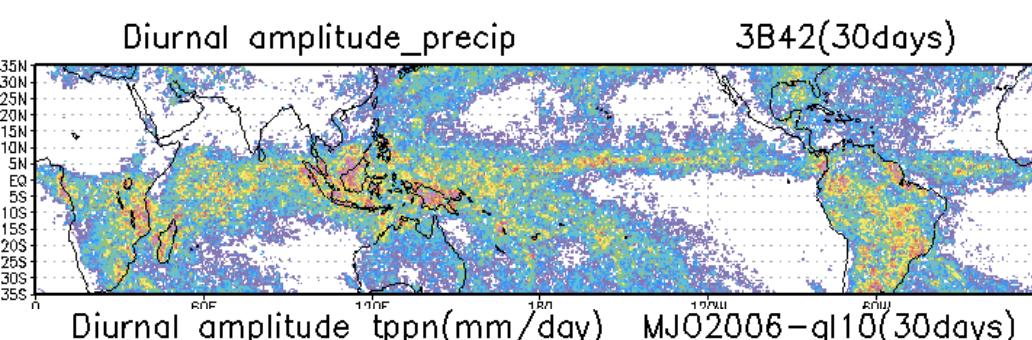
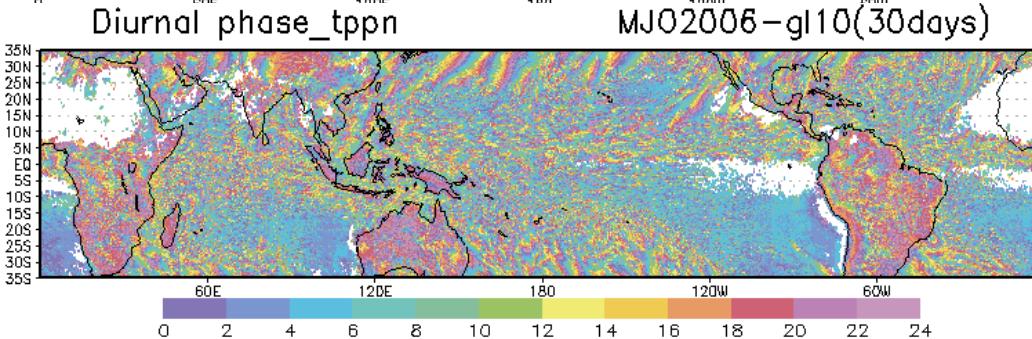
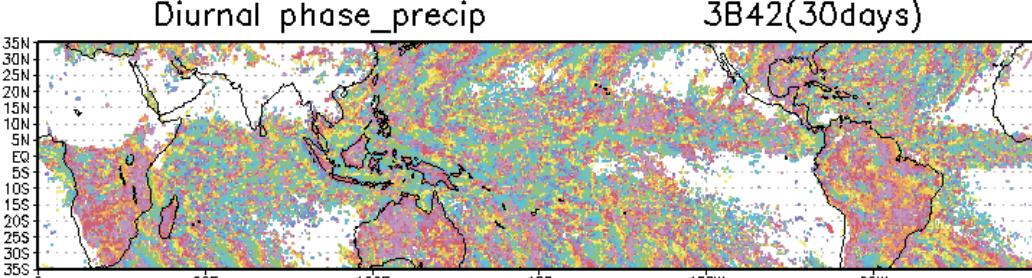
**Cloud height vs MSLP**

# NICAM SIMULATIONS

- MJO simulations
- Tropical cyclones
- Monsoon simulations, ISVs and TCs
- **Diurnal variability, cloud properties**

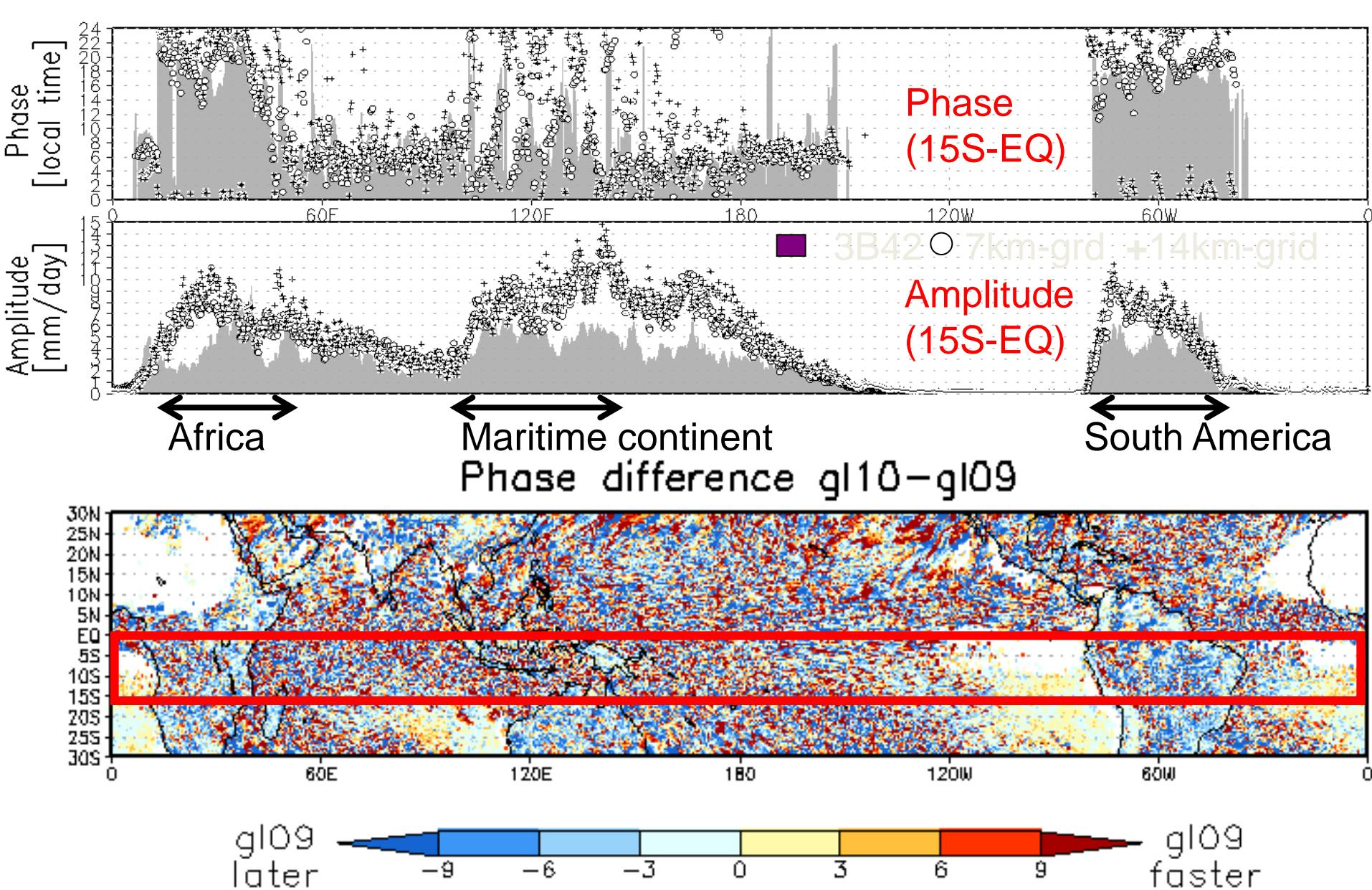
# Diurnal variation of precipitation

Phase



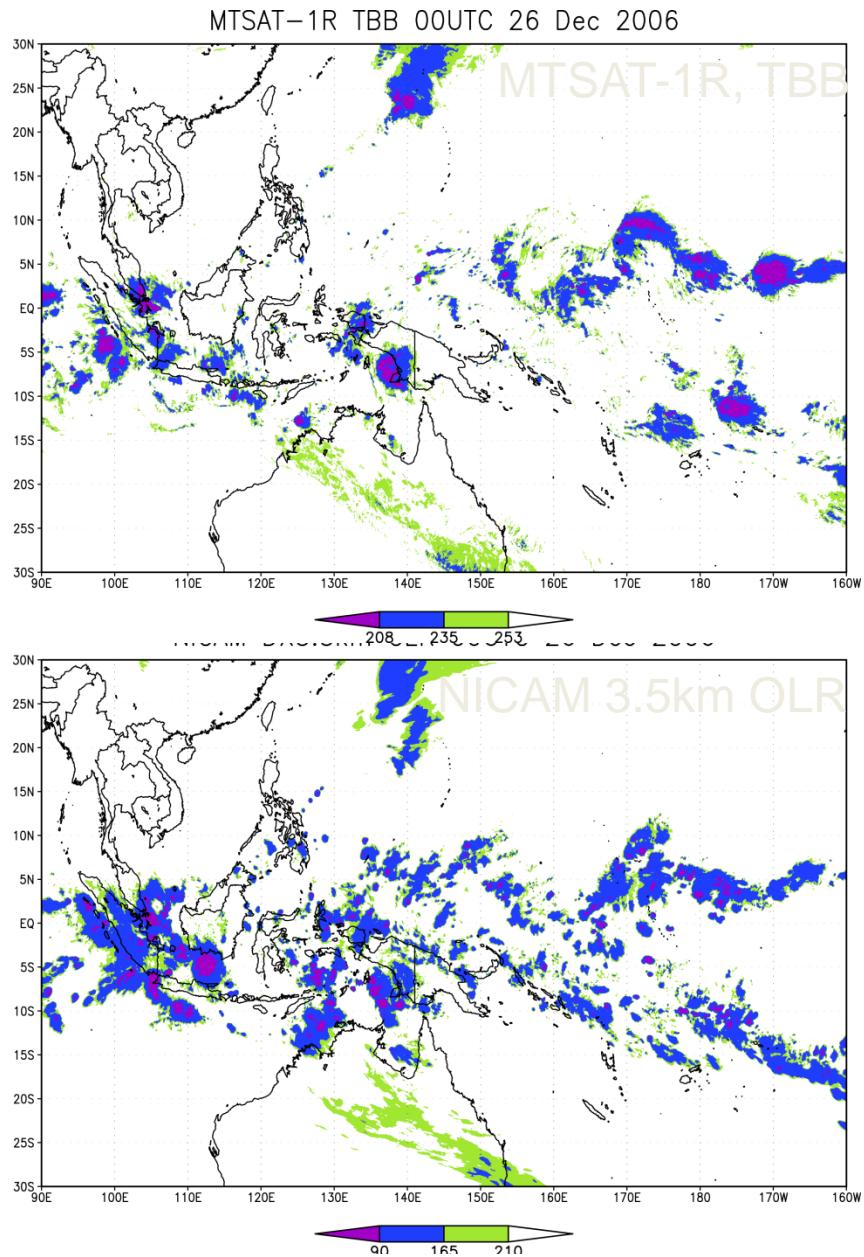
Amplitude

NICAM 7km vs TRMM 3B42  
15 Dec 2006-15 Jan 2007  
Sato et al.(2009, *J. Clim*)

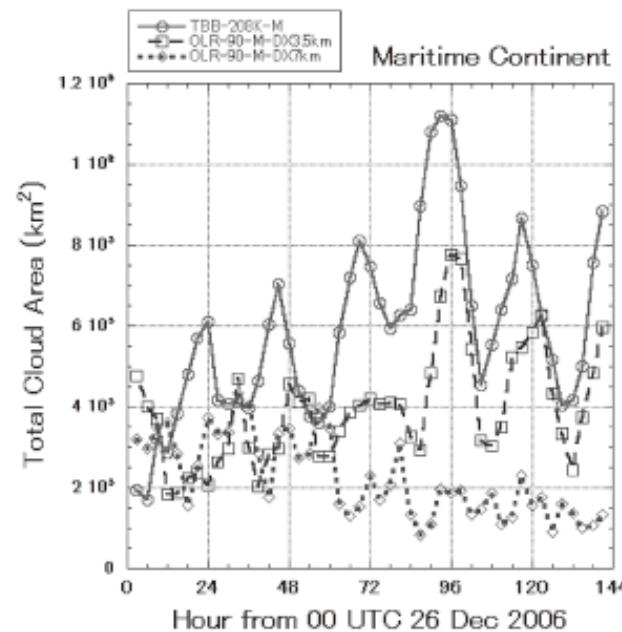


- Improvement of phase and amplitudes from 14km-mesh to 7km-mesh

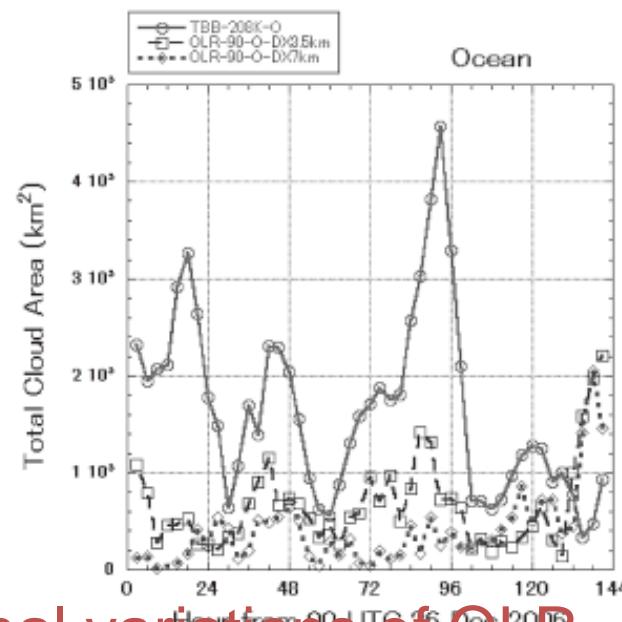
# Cloud clusters: NICAM 3.5km at 00UTC 26 Dec 2006



MTSAT-1R  
TBB



NICAM  
DX3.5km

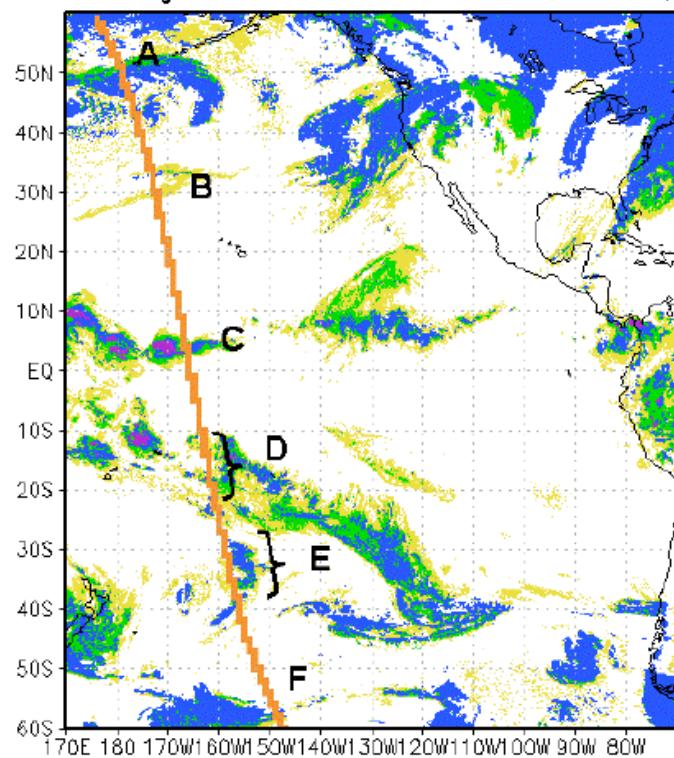


Diurnal variations of OLR

# Ice cloud evaluation by split windows

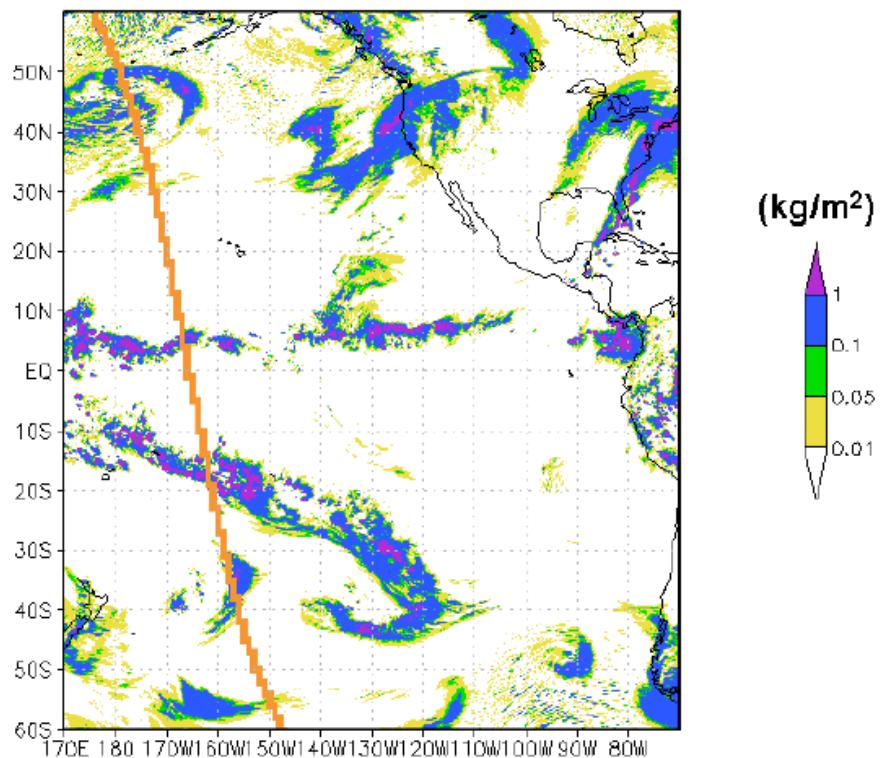
GOES-W Cloud ice(split window)

GOES-W High-level Cloud 00UTC 26 Dec, 2006



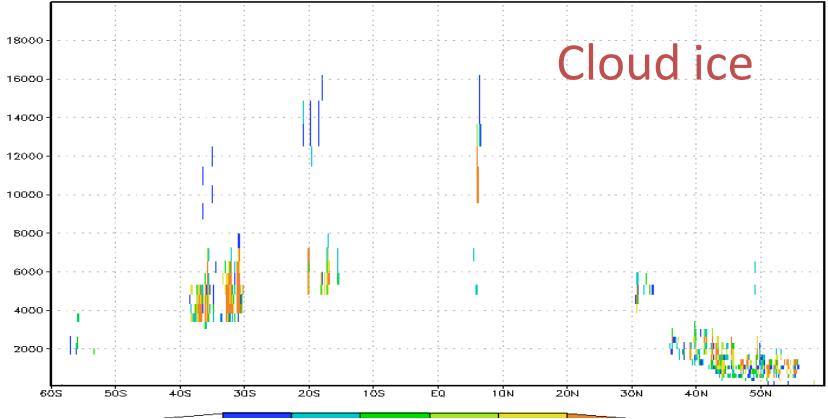
NICAM 3.5km Cloud Ice+snow

NICAM ICE+SNOW 00UTC 26 Dec, 2006

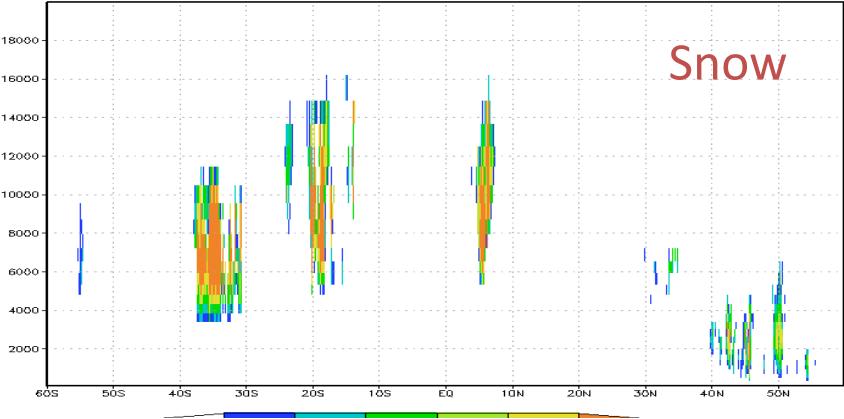


Inoue, T., Satoh, M., Hagihara, Y., Miura, H., Schmetz, J. (2009)  
Comparison of high-level clouds represented in a global cloud-system  
resolving model with CALIPSO/CloudSat and geostationary satellite  
observations. *J. Geophys. Res.*, submitted

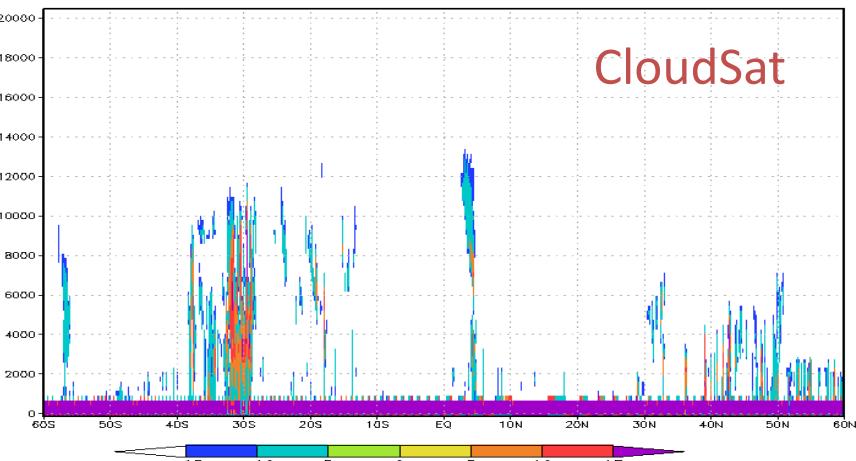
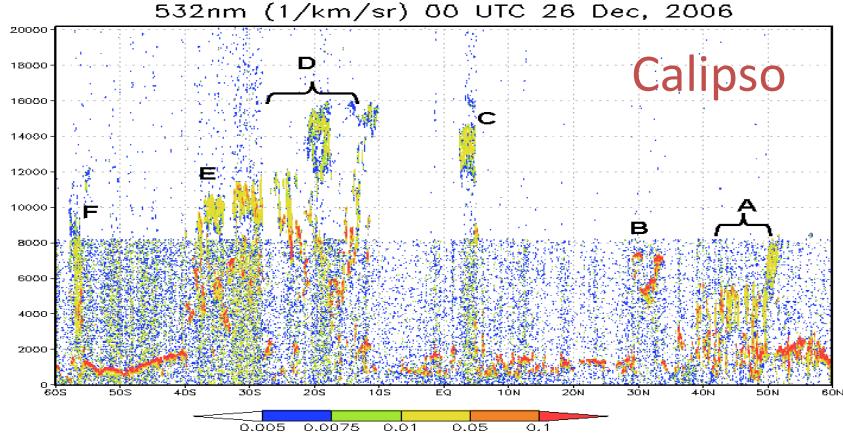
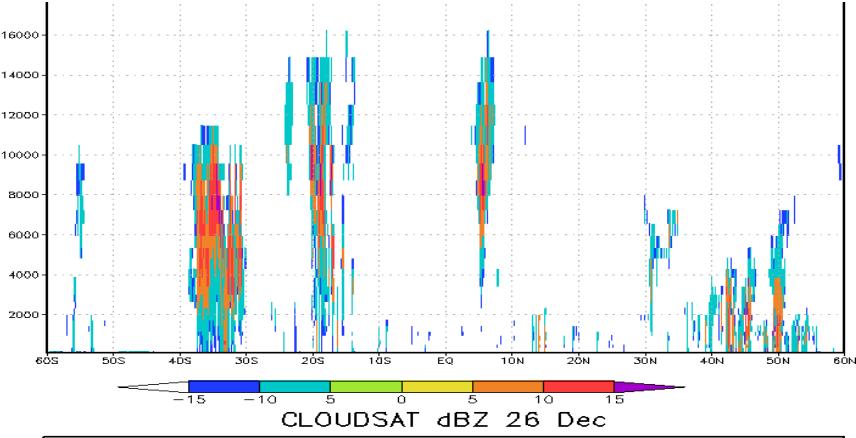
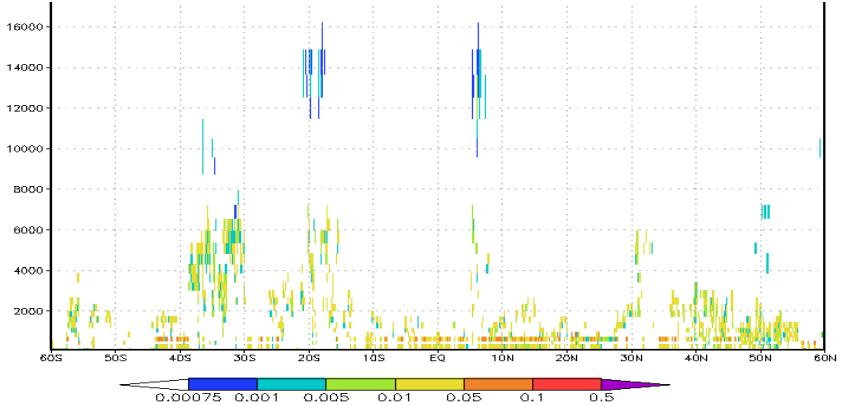
NICAM ICE PROFILE 26 Dec



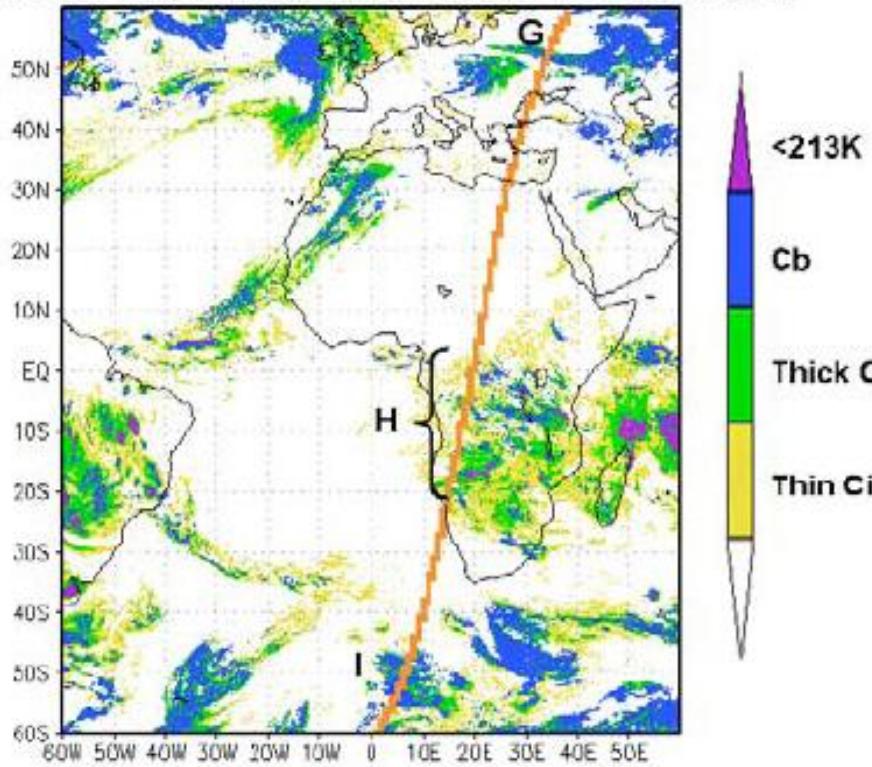
NICAM SNOW PROFILE 26 Dec



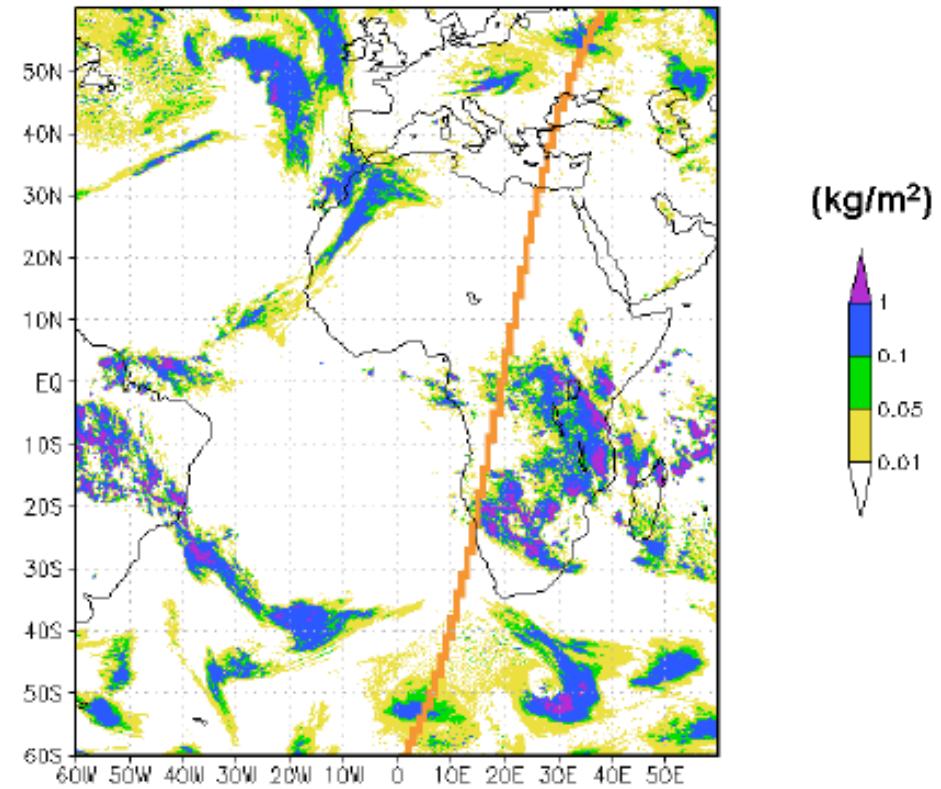
## Calipso/CloudSat simulated reflectivities by COSP



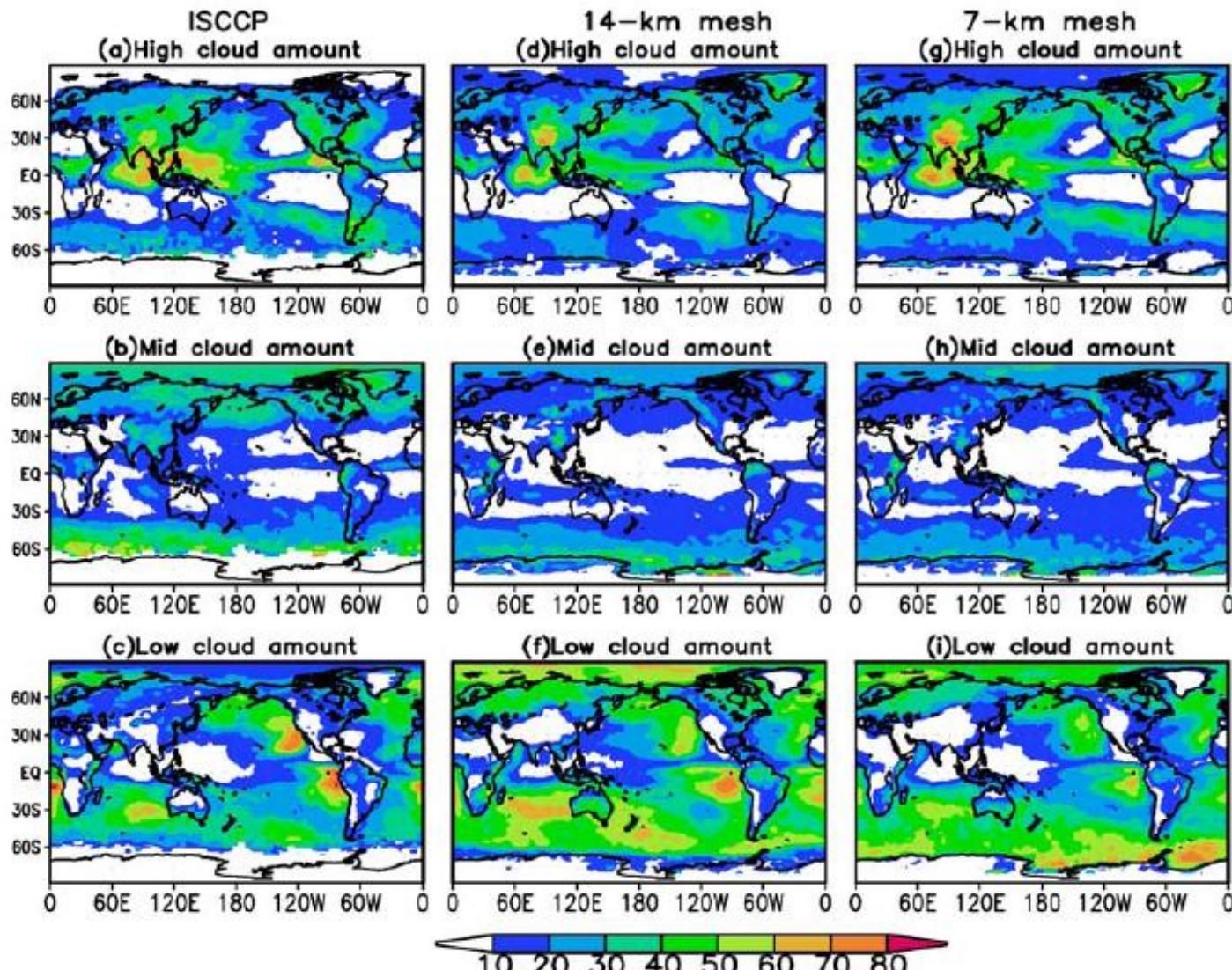
METEOSAT High-level Cloud 00UTC 29 Dec, 2006



NICAM ICE+SNOW 00UTC 29 Dec, 2006



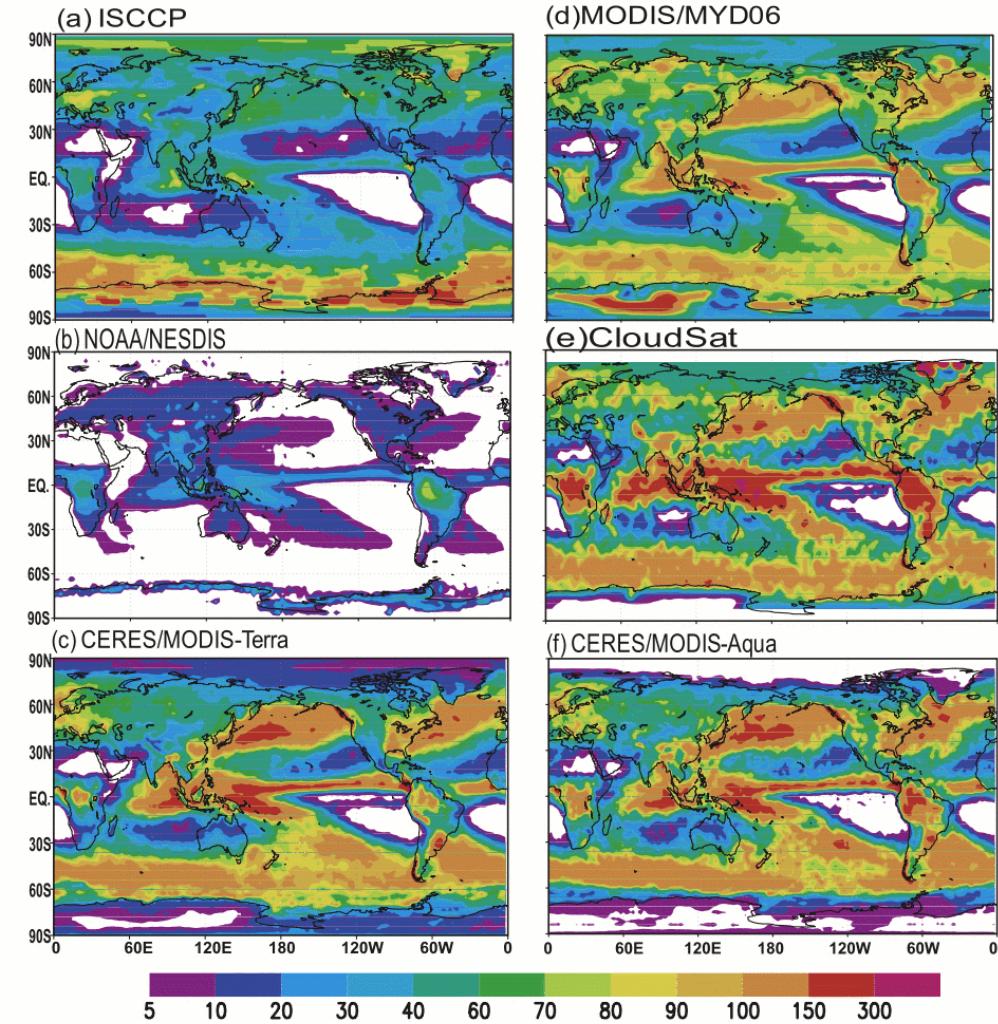
# Cloud fractions



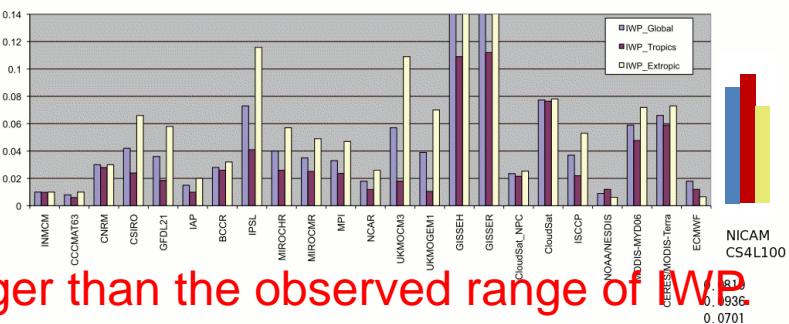
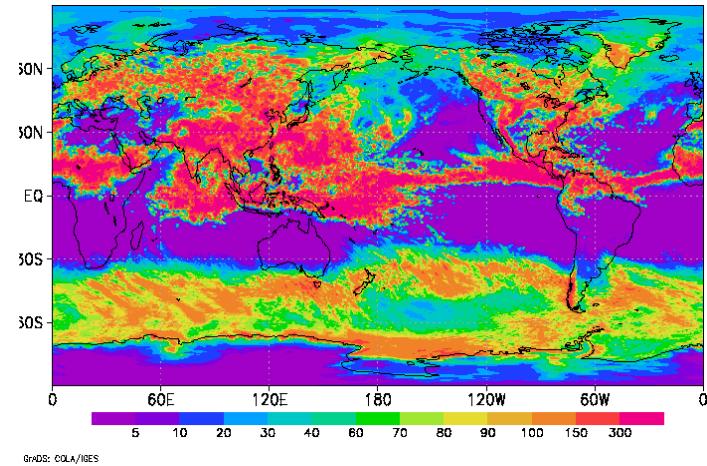
Noda et al. (2009) Importance of the subgrid-scale turbulent moist process: cloud distribution in global cloud-resolving simulations. Atmospheric Research, in press.

# Ice clouds

observation



IWP



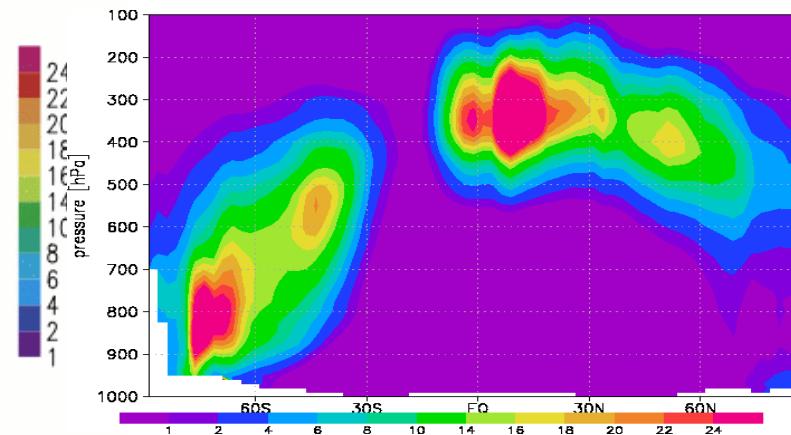
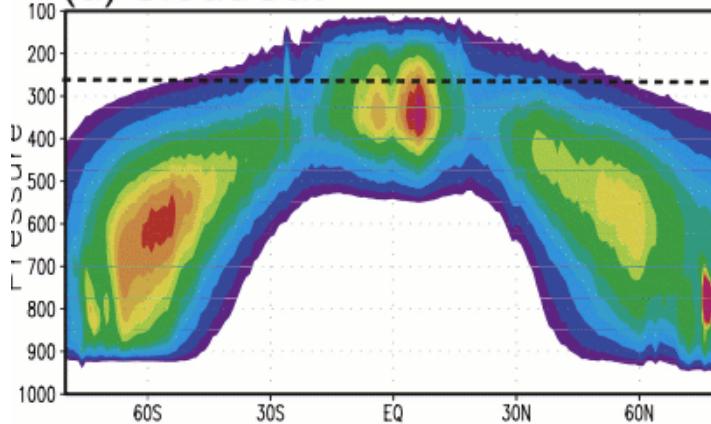
NICAM IWP is larger than the observed range of IWP

Waliser et al. (2009)

# Ice Water Contents

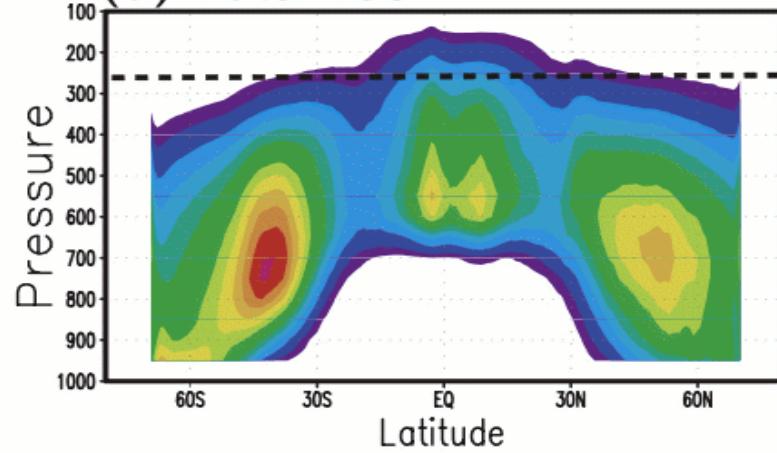
NICAM CS4L100

(d) CloudSat

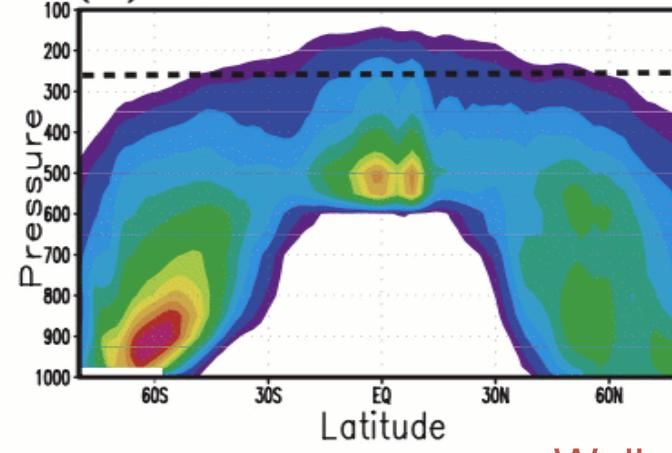


NICAM IWC  
is larger in  
the tropics

(d) Total Ice



(h) Total Ice



RAVE

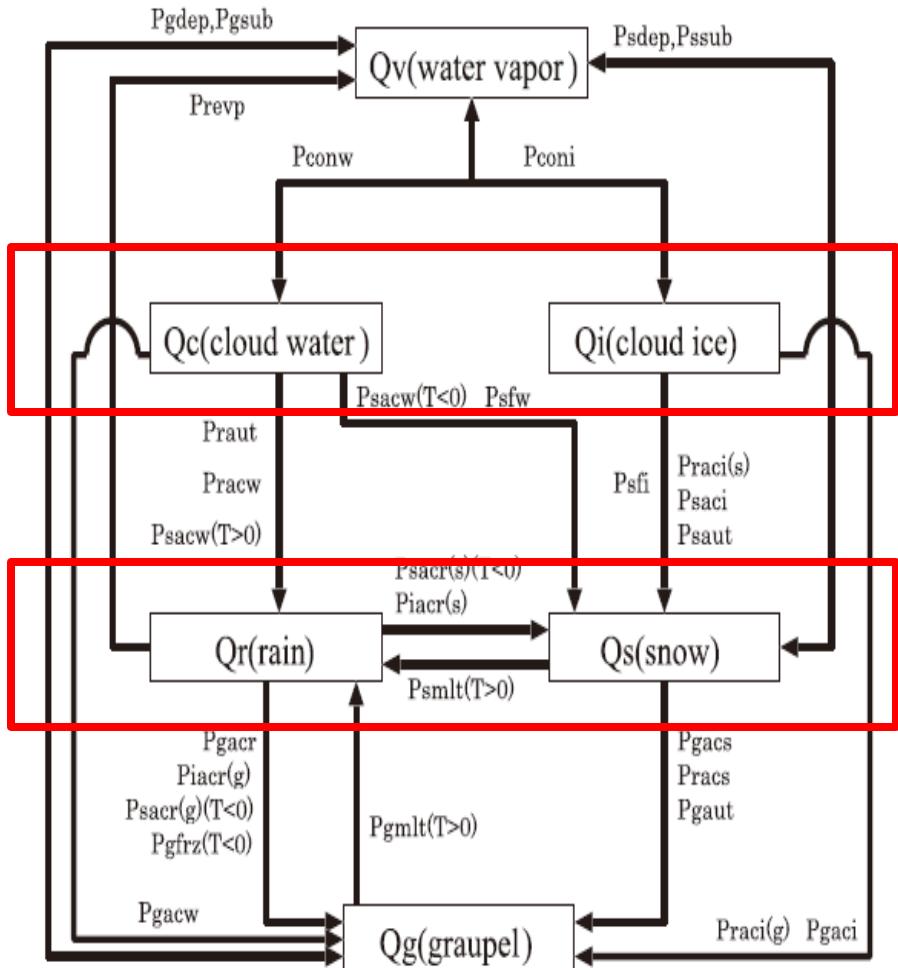
fvMMF

Waliser et al. (2009)

Iga et al. (2009, in prep.)

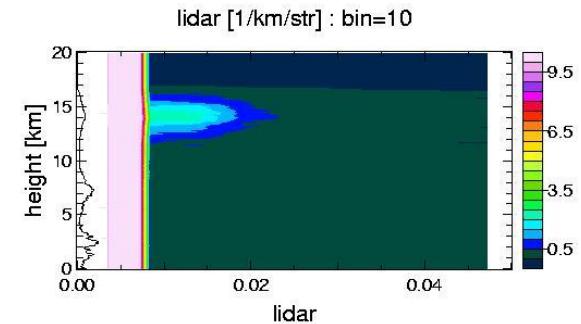
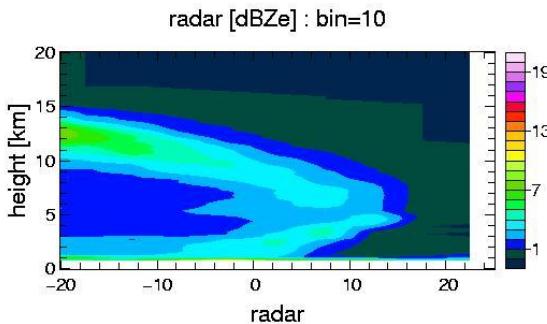
# Cloud Microphysics Schemes of NICAM

- Grabowski (1998)
  - NSW6 (Tomita 2008,JMSJ)
    - Single-moment 6-categories of water
  - NDW6 (Seiki)
    - Double-moment 6-categories of water
- After Seifert and Beheng (2006)

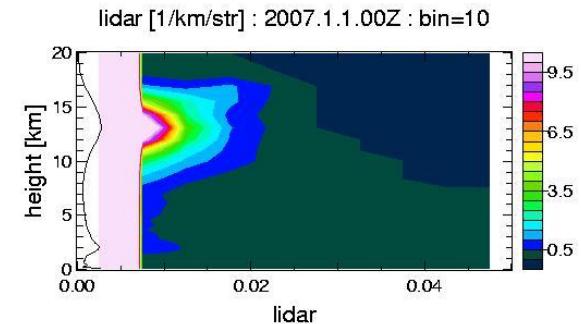
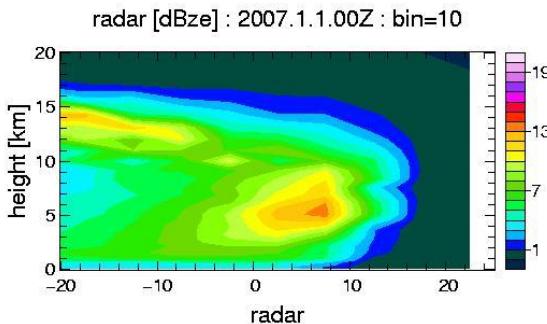


# Sensitivity to cloud microphysics schemes: CFADS - maritime continent region in the tropics use of the satellite simulator COSP

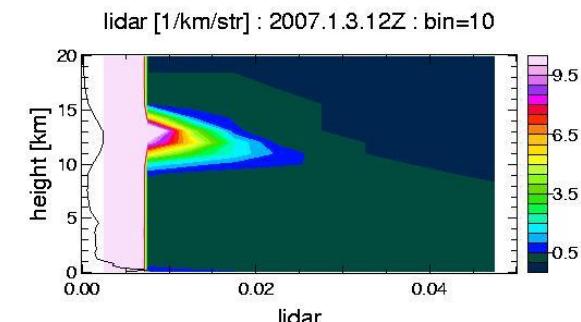
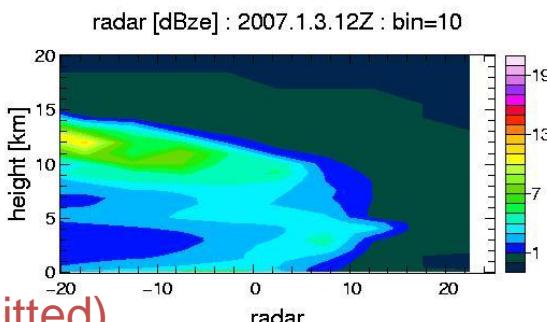
CloudSat/CALIPSO



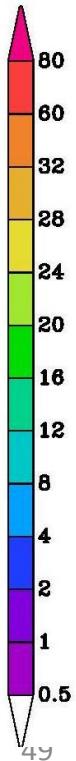
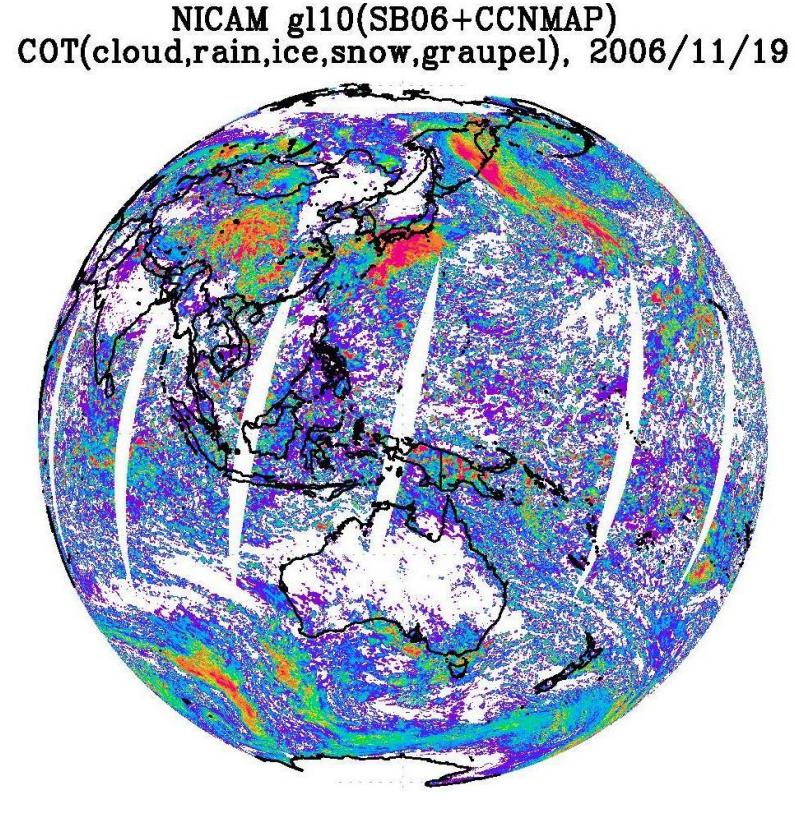
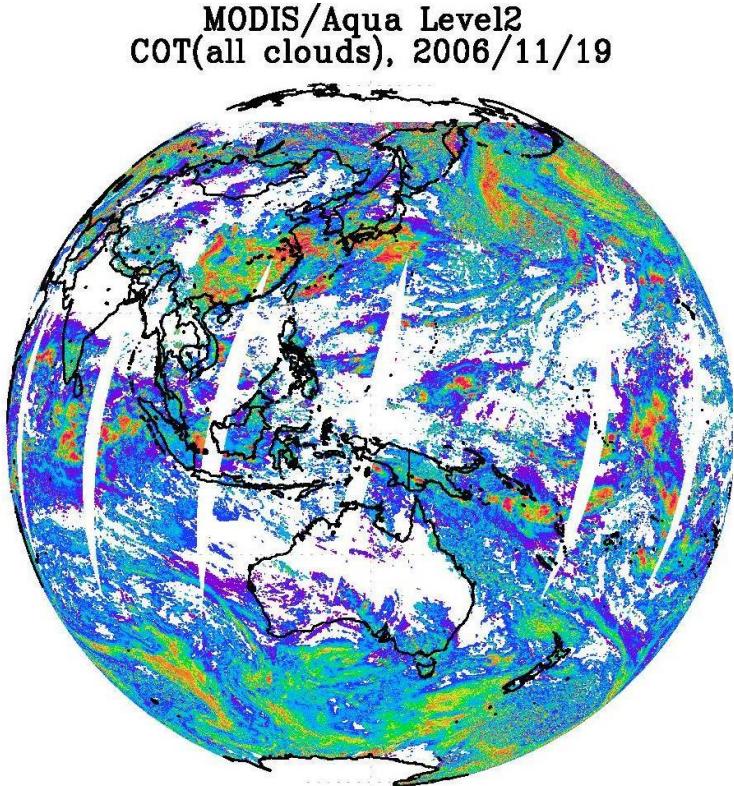
NICAM-GCRM 3.5km, Grabowski(1998)



NSW6 (Tomita 2008), stretched-NICAM <5km

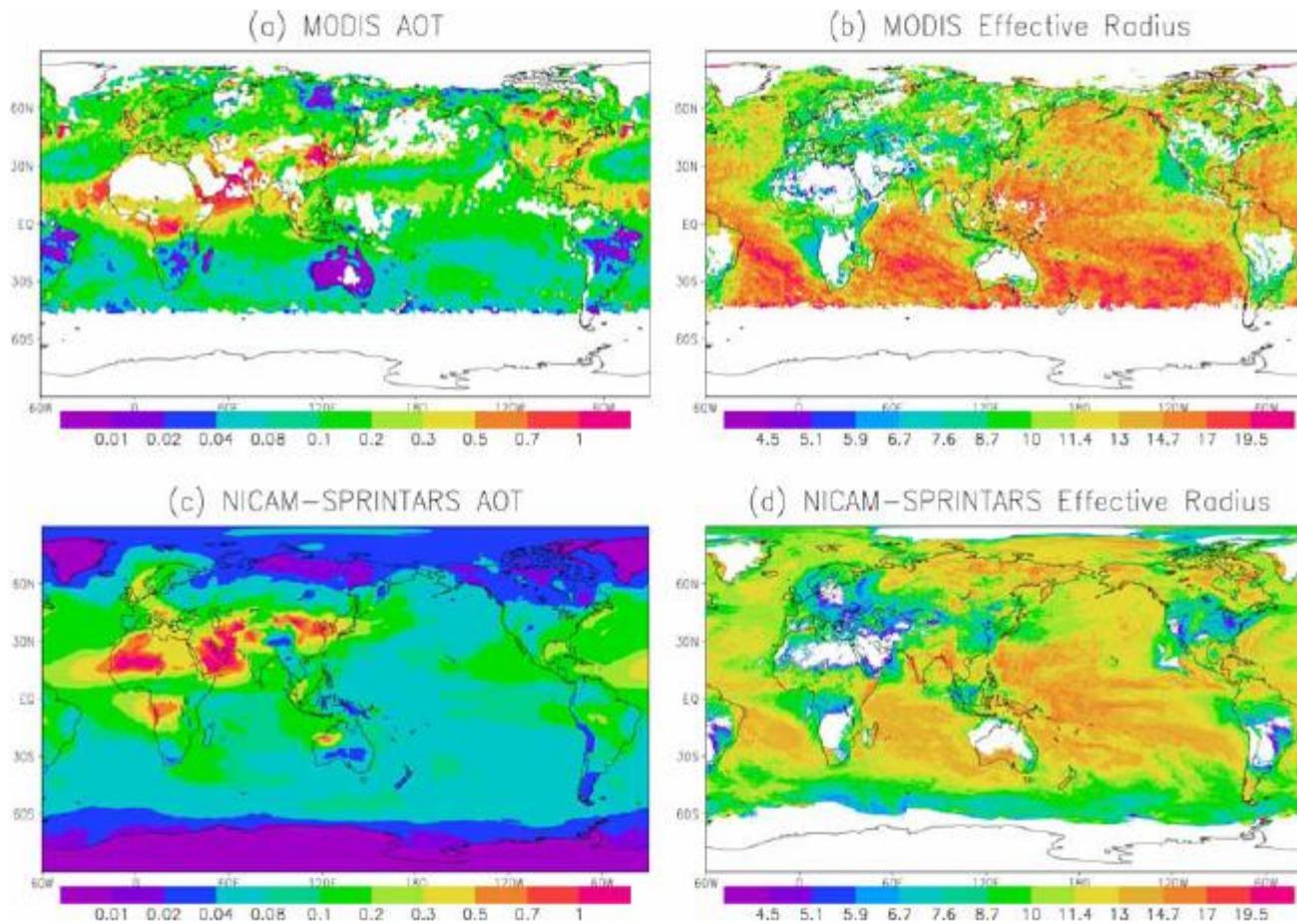


Pilot simulations of 2-moment cloud model with  
Global 7km resolution.  
Comparisons with satellites and further challenges.  
(Validation of 2-moment cloud model  
Seiki Tatsuya.(CCSR, Univ. of Tokyo)



# Aerosols interactions

Suzuki et al. (2008) Global cloud-resolving simulation of aerosol effect on warm clouds. Geophys. Res. Letters, 35, L19817, doi:10.1029/2008GL035449.



# NICAM development

- On going & near future
  - Cloud microphysics scheme: single moment bulk, NSW6, double moment bulk, NDW6
  - Aerosols coupling (SPRINTARS)
  - Boundary layer scheme: MYNN2.5, 3
  - Dynamics: step mountains
  - Coupling to ocean models (COCO)
  - Assimilation LETKF (Kondo and Tanaka 2009,SOLA)
  - 3D radiation (Iwabuchi 2006,JAS)  
& bin microphysics (Iguchi) for references
- Use of 10PF super computer in Kobe (2012-)
  - 10 years time slice exp.
    - AMIP-type, future time slice exp
  - 400m-mesh global runs
  - AO-coupled model; climate simulations

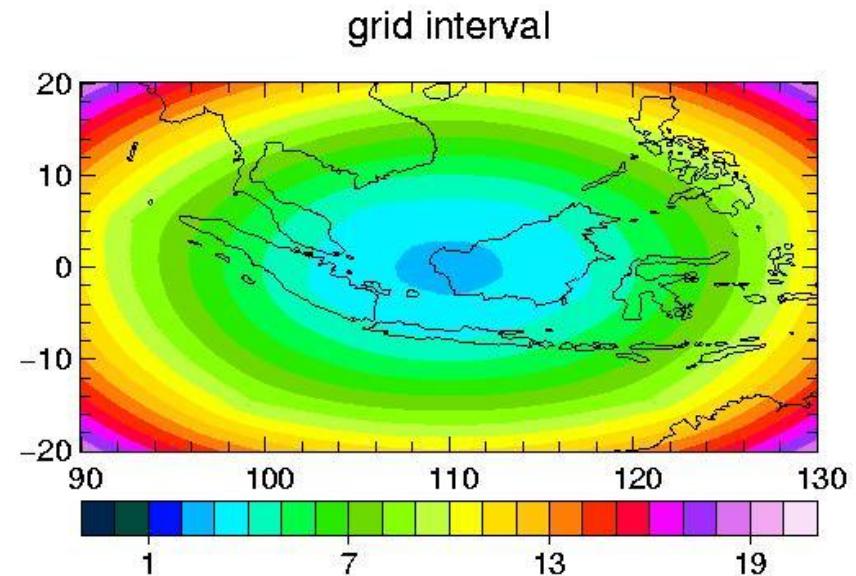
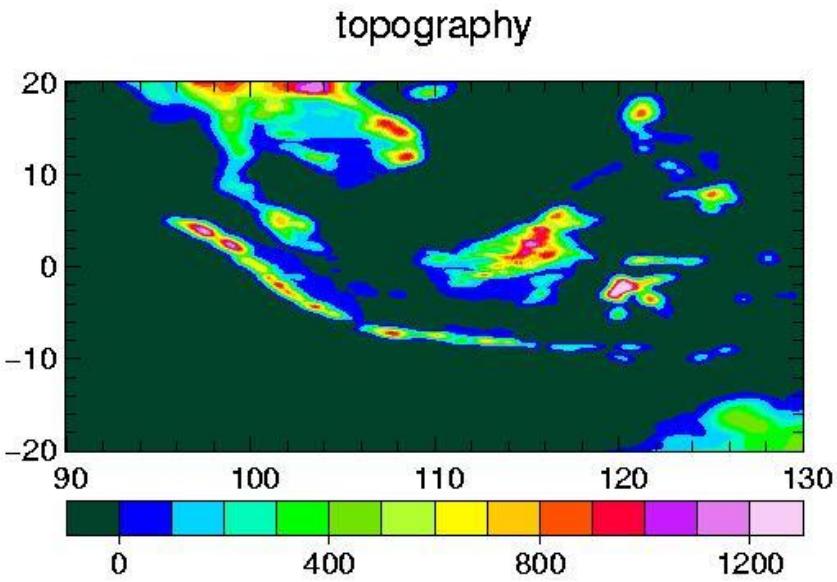


# Summary and final remarks

- NICAM simulates
  - good ISVs, TCs, and diurnal variations
  - multiscale structures of tropical convection
  - good cloud properties (high/low) with improved schemes
- Known biases
  - Stronger precipitation
  - TC numbers, depend on physics and resolutions
- Development on going
- Data and model available for collaborations
  - Further information <http://nicam.jp>



# Stretch-NICAM exp.



- Use of NICAM as a regional model: local-CRM

Tomita (2008, JMSJ)

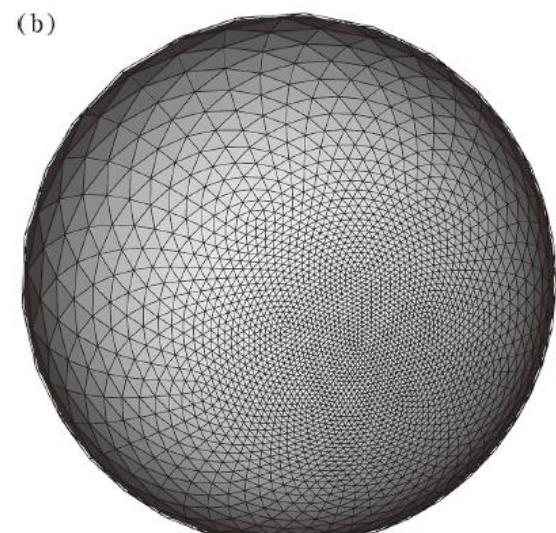
- $\Delta x = 2.5\text{km}-250\text{km}$

Stretch factor=10, Glevel8

- Integration: 2007.1.1.12-1.5.12

- Sensitivity to cloud microphysics scheme: NSW6

Satoh et al. (2009, JGR, submitted)



# Nonhydrostatic scheme

$$\frac{\partial}{\partial t} R + \nabla_h \cdot \mathbf{V}_h + \frac{\partial}{\partial \xi} \left( \frac{W}{G^{1/2}} + \mathbf{G}^3 \cdot \mathbf{V}_h \right) = 0$$

$$\frac{\partial}{\partial t} \mathbf{V}_h + \nabla_h P + \frac{\partial}{\partial \xi} (\mathbf{G}^3 P) = \mathbf{ADV}_h + \mathbf{F}_{Coriolis}$$

$$\frac{\partial}{\partial t} W + \frac{\partial}{\partial \xi} \left( \frac{P}{G^{1/2}} \right) + Rg = ADV_z + F_{z,Coriolis}$$

$$\frac{\partial}{\partial t} E_{total} + \nabla_h \cdot [\mathbf{U} + k + \Phi] \mathbf{y}_h - \frac{\partial}{\partial \xi} \left[ \mathbf{U} + k + \Phi \left( \frac{W}{G^{1/2}} + \mathbf{G}^3 \cdot \mathbf{V}_h \right) \right] = 0$$

## Prognostic variables

- density
- horizontal momentum  $R = G^{1/2} \rho$
- vertical momentum  $\mathbf{V}_h = G^{1/2} \rho \mathbf{v}_h$
- total energy  $W = G^{1/2} \rho w$

$$E_{total} = \rho G^{1/2} [\mathbf{U}_{in} + k + \Phi]$$

## Metrics

$$G^{1/2} = \left( \frac{\partial z}{\partial \xi} \right)_{x,y}$$

$$\mathbf{G}^3 = \nabla_h \xi$$

$$\xi = \frac{H(z - z_s)}{H - z_s}$$

# Computational Performance

Table 2 Computational performance of the aqua planet experiments with NICAM.

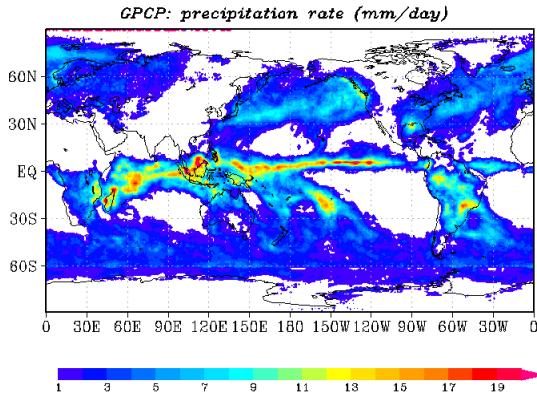
NICAM	glevel 9	glevel 10	glevel 11
$\Delta x$	14 km	7 km	3.5 km
$\Delta t$ [sec]	30	30	15
nodes	80	320	320
1 day time [hr]	0.64	0.81	5.28
GFLOPS	1911.8	7607.6	7701.5
sustained performance[%]	37.3	37.1	37.6

Satoh et al.(2005, *J. Earth Simulator*)

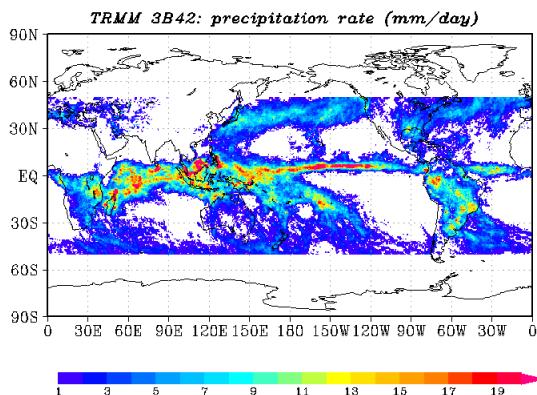


# 30-day mean: precipitation

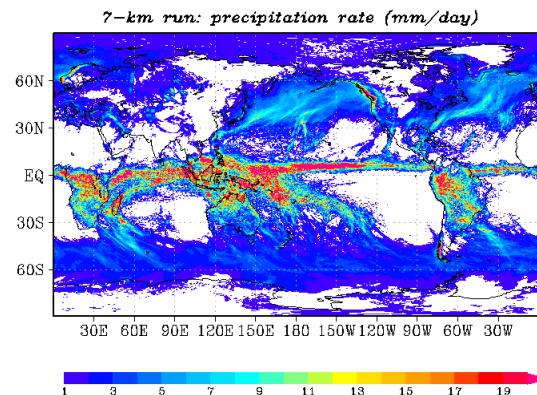
GPCP



TRMM 3B42

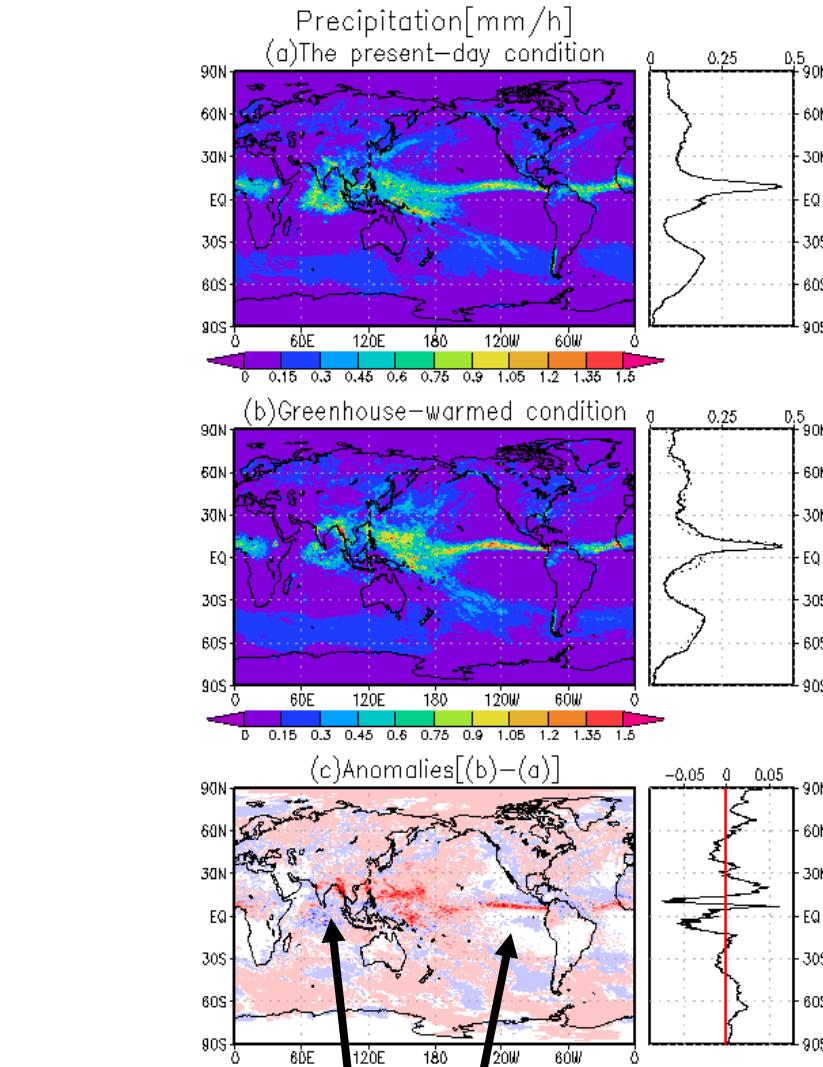
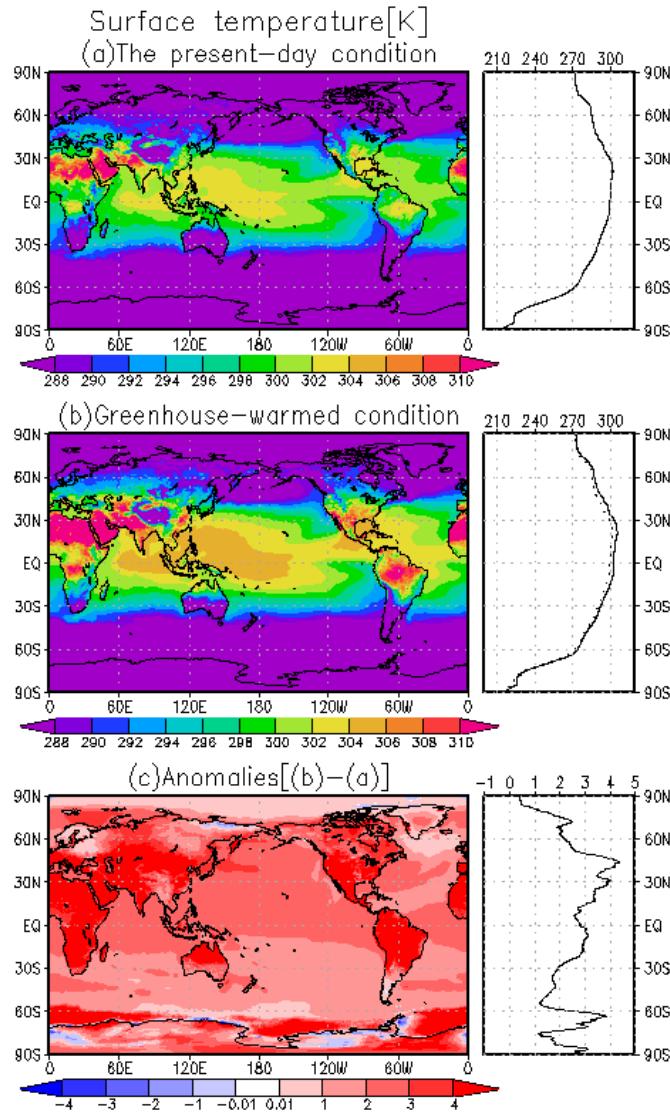


7-km run



- The spatial structure was reproduced reasonably.
- Precipitation rate was overestimated in the tropics.

# Temperature and precipitation change for global change time slice JJA GW condition - present, $dx \sim 14\text{km}$



Concentration of ITCZ  
More precipitation in South Asia

Geo-stationary satellite  
(MTSAT-1R) Infrared image

NICAM 3.5km-grid mesh  
Simulation  
Outgoing Longwave Radiation  
(OLR)

